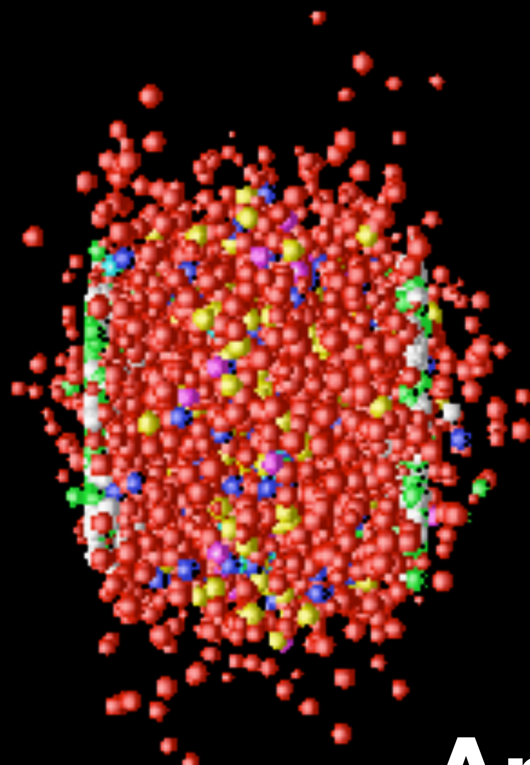
compare apples...

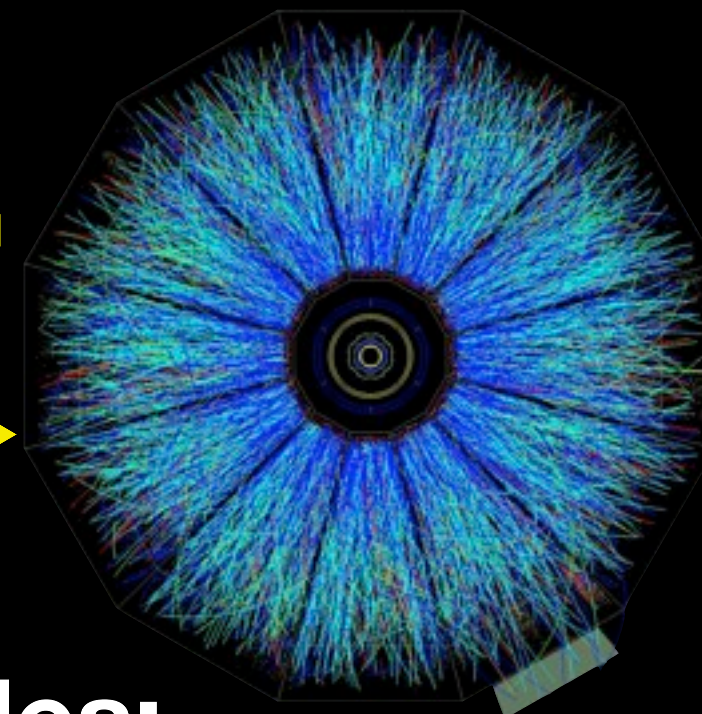
...w/ apples ...not oranges ...or lemons

Apples with apples:
comparing initial states in theory & experiment

Peter Steinberg
Brookhaven National Laboratory

TECHQM/CATHIE Workshop
December 14, 2009





Apples with apples: comparing initial states in theory & experiment

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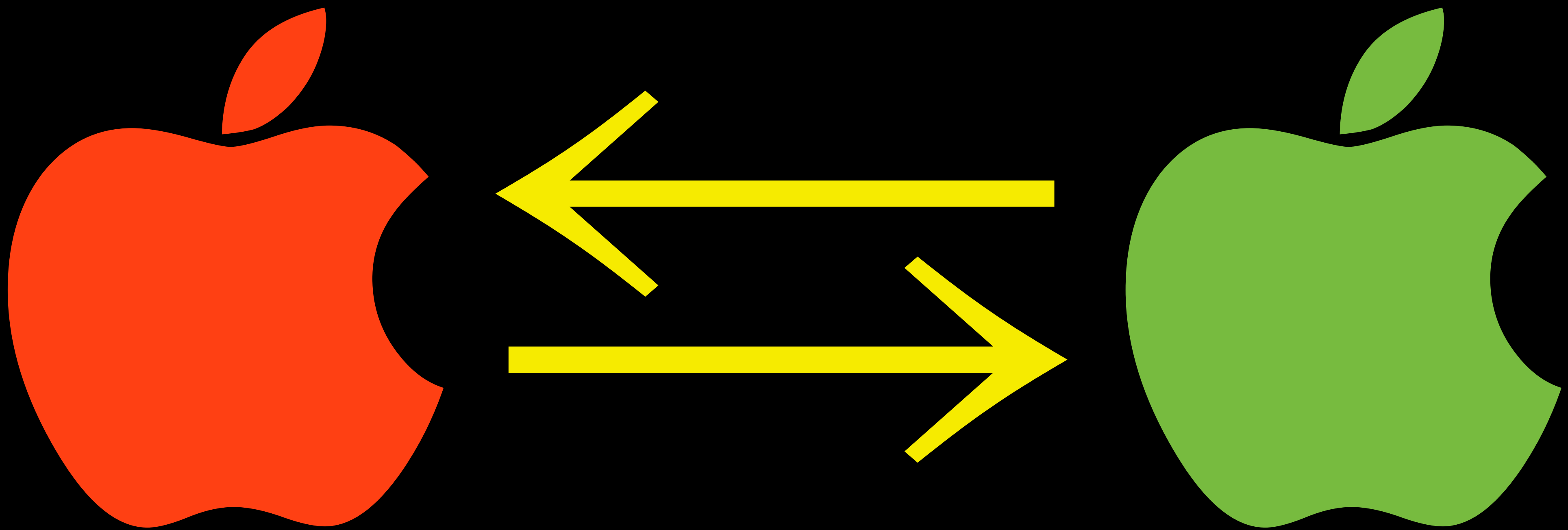
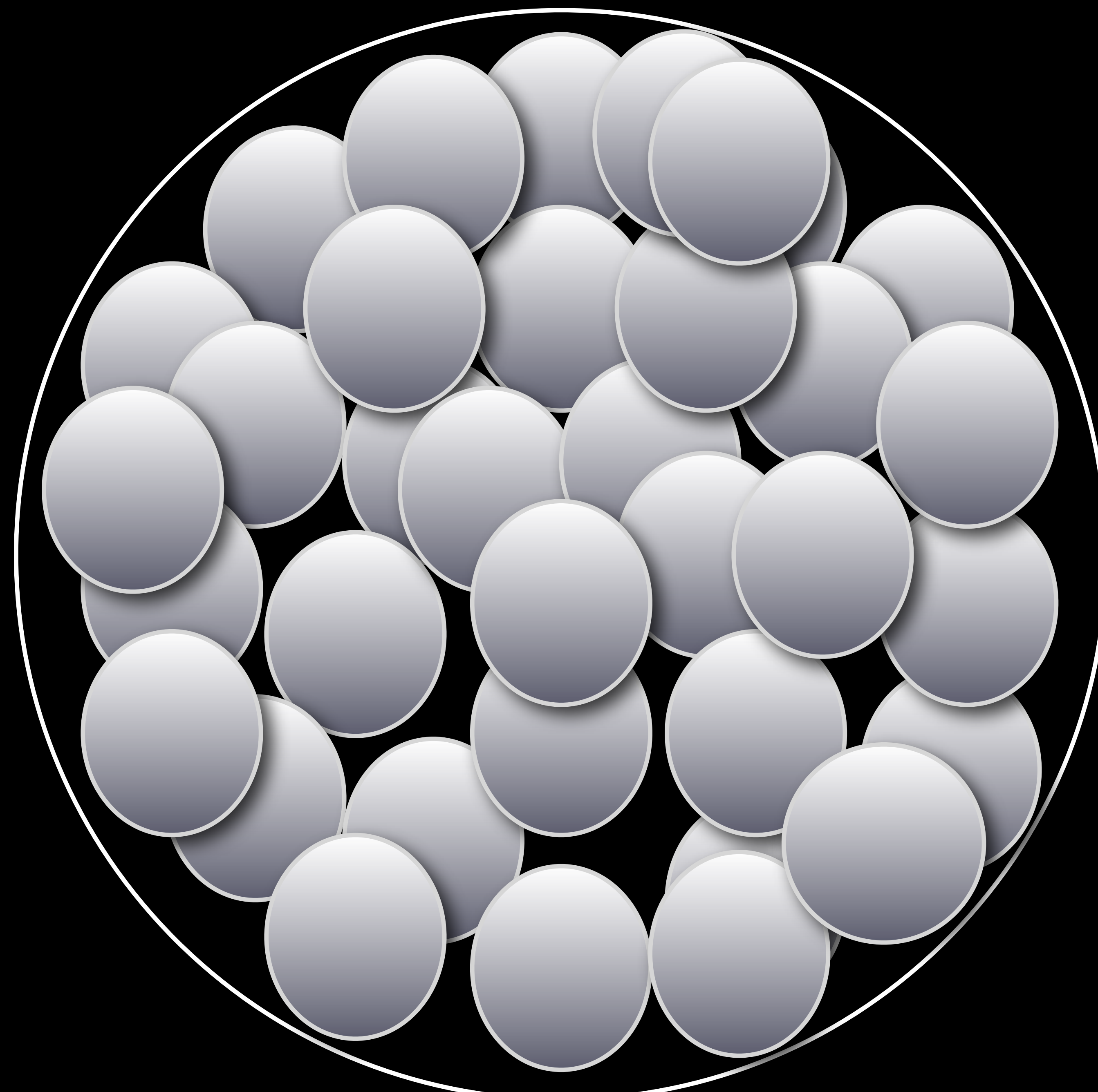
Acknowledgements

- **Many of the issues discussed in this talk arose in the writing of several papers:**
  - "Glauber Modeling in High Energy Nuclear Collisions"
    - *M. Miller, K. Reygers, S.J. Sanders, & PAS http://arXiv.org/abs/nucl-ex/0701025*
  - "The importance of correlations and fluctuations on the initial source eccentricity in heavy ion collisions"
    - *B. Alver, M. Baker, U. Heinz, C. Loizides, S. Manly (& PHOBOS!) http://arXiv.org/abs/0711.3724*
  - "Quantitative and Conceptual Considerations in Extracting the Knudsen Number in Heavy Ion Collisions"
    - *J. Nagle, PAS & W.A. Zajc, http://arXiv.org/abs/0908.3684*
- **Thanks to my collaborators!**

Optical vs. MC Glauber



What is a Nucleus?



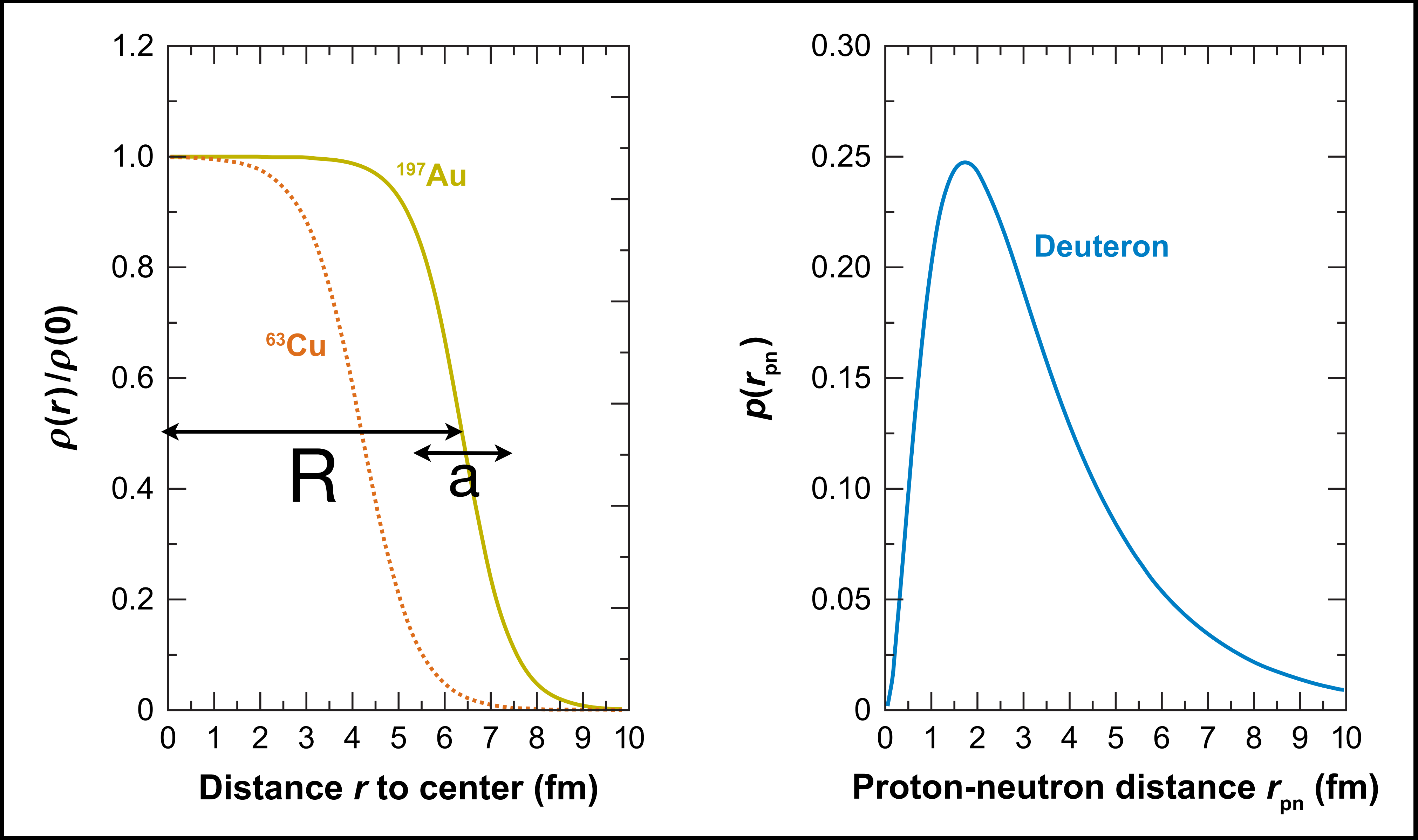
A bound state of nucleons, with positions chosen according to the Fermi distribution

What is a Nucleus?

An average density distribution of nucleon positions

Ann.Rev.Nucl.Part.Sci.57:205-243,2007

Nuclear Distributions



Distributed according to a Fermi distribution
(or Hulthen, for d+Au)

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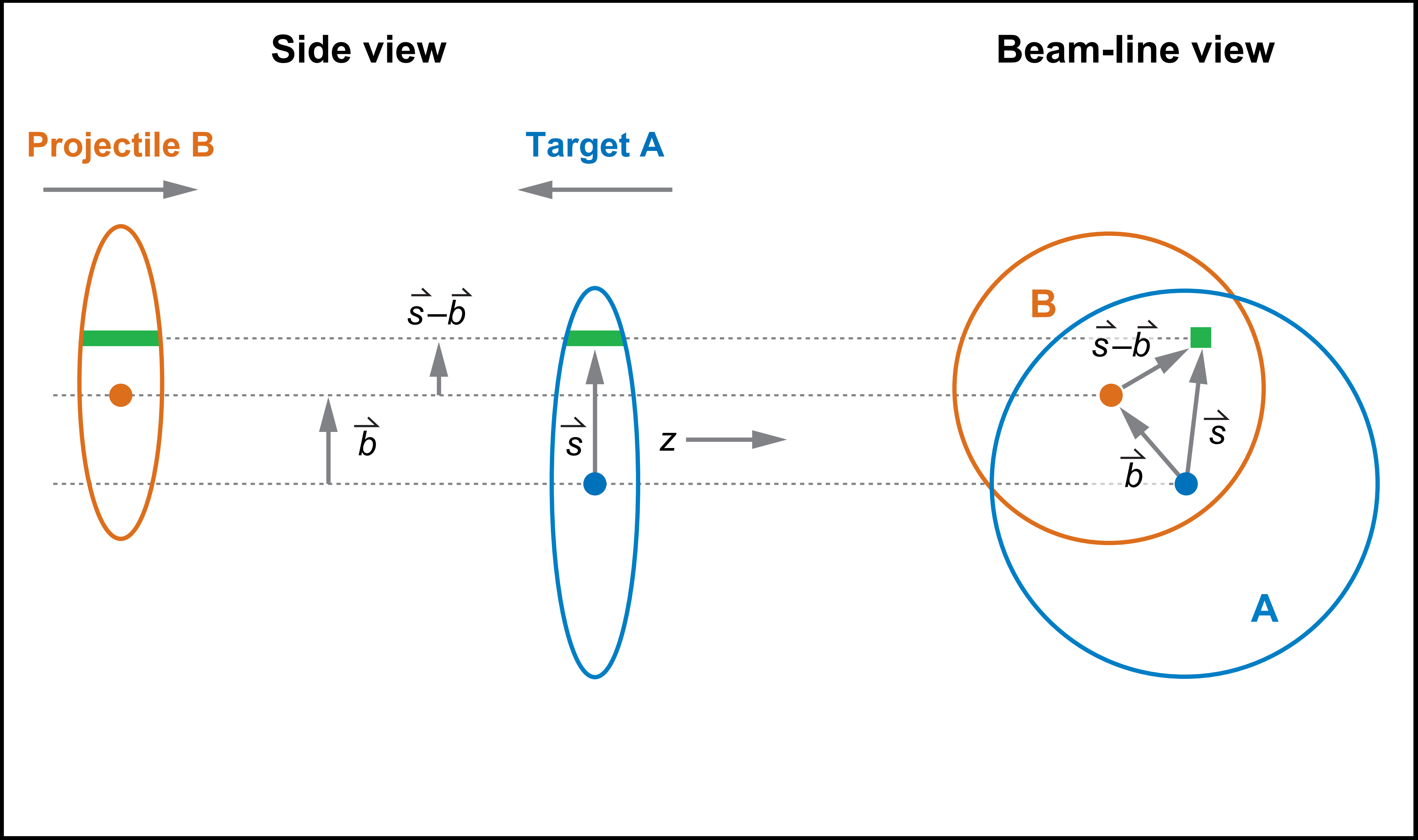
Optical Limit Approach



$$\sigma_{AB} = \int d^2b \left\{1 - \left[1 - \sigma_{inel}^{NN} T_{AB}(b)\right]^{AB}\right\}$$

everything based on smooth, averaged densities

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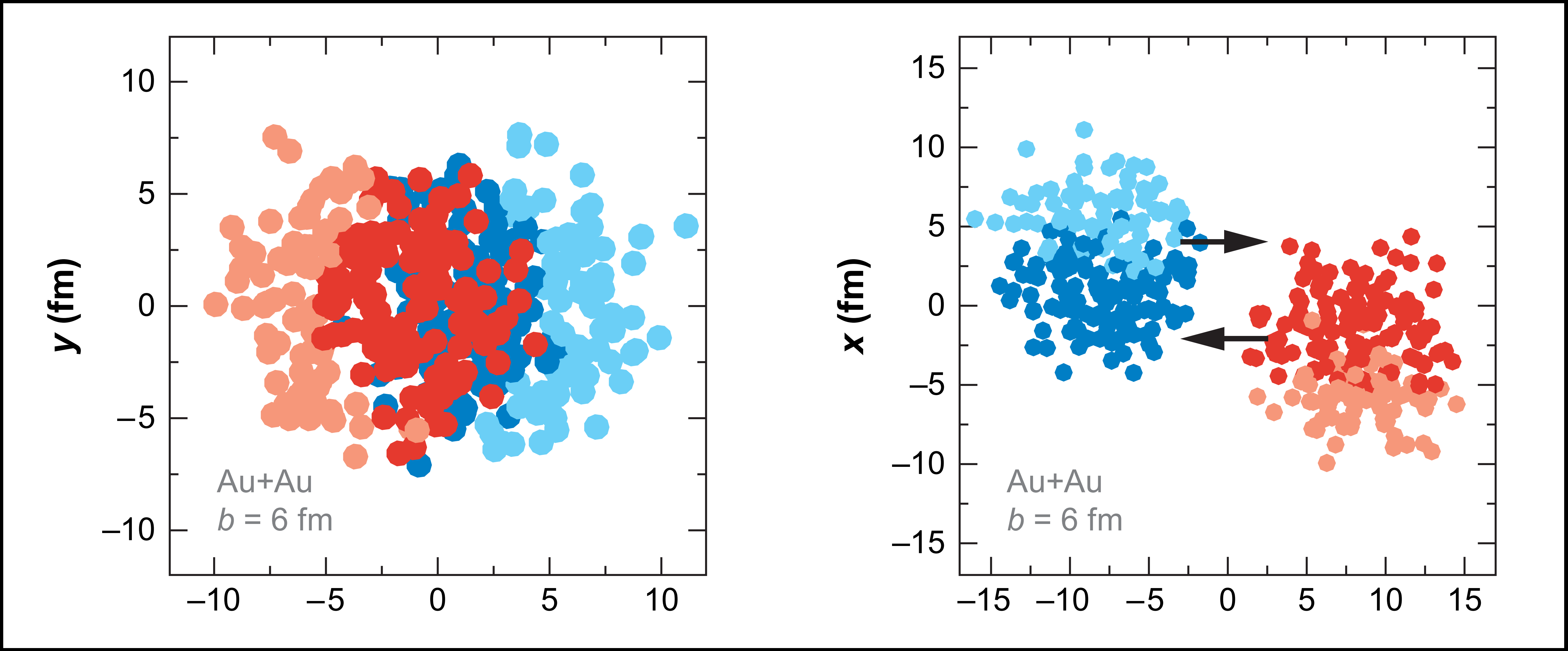
Glauber Monte Carlo



$$\sigma_{inel}^{AB} = \int d^2b \int d^2s_1^A \cdots d^2s_A^A d^2s_1^B \cdots d^2s_B^B \times$$
$$\hat{T}_A(\mathbf{s_1^A}) \cdots \hat{T}_A(\mathbf{s_A^A}) \hat{T}_B(\mathbf{s_1^B}) \cdots \hat{T}_B(\mathbf{s_B^B}) \times$$
$$\left\{ 1 - \prod_{j=1}^{B} \prod_{i=1}^{A} [1 - \hat{\sigma}(\mathbf{b} - \mathbf{s_i^A} + \mathbf{s_j^B})] \right\}$$

A complicated 800-dimensional integral, evaluated by MC methods

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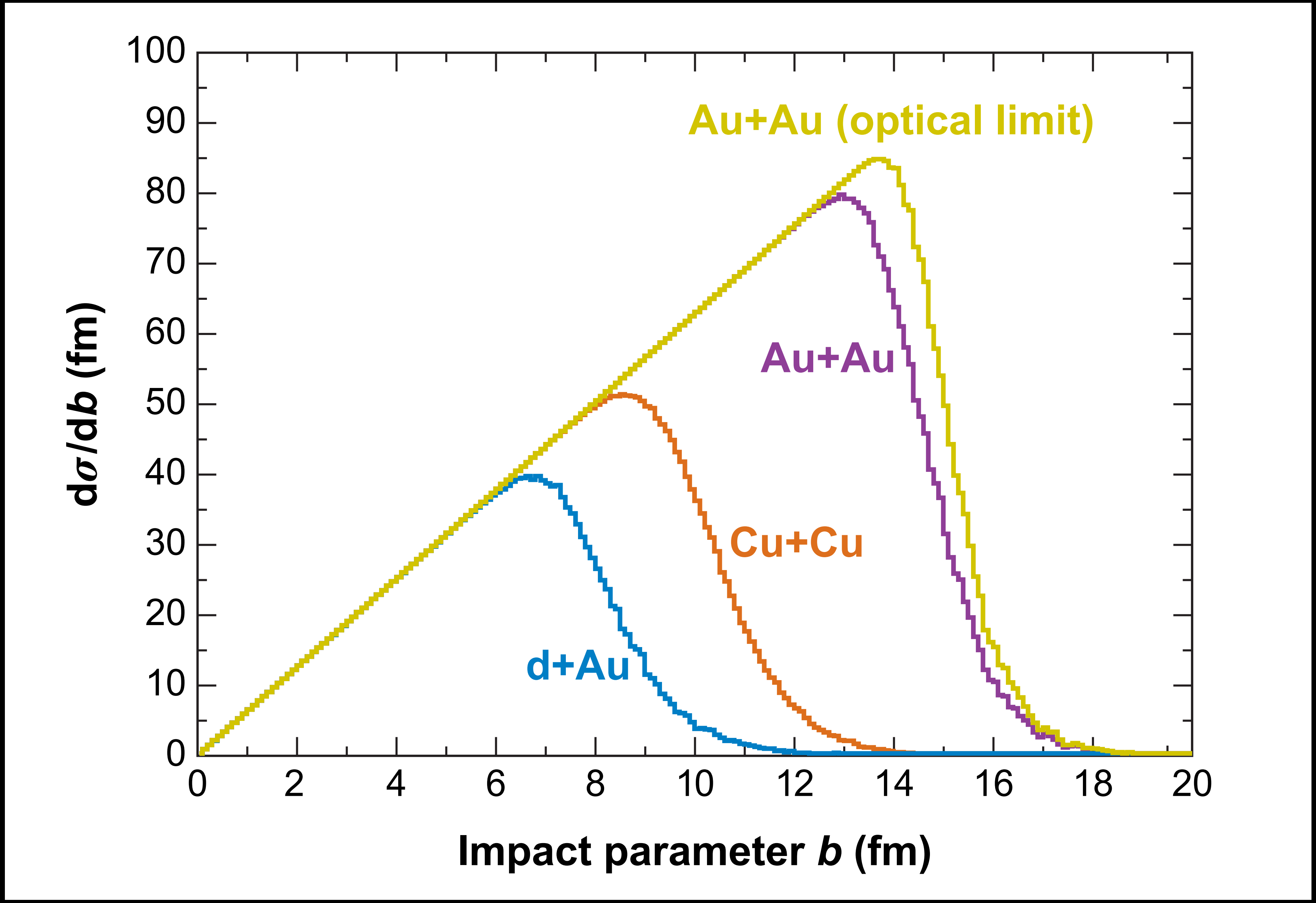
Effect on Total Cross Section



Total cross section systematically <u>larger</u> in optical approach

"Eclipsing"

PHYSICAL REVIEW VOLUME 100, NUMBER 1 OCTOBER 1, 1955

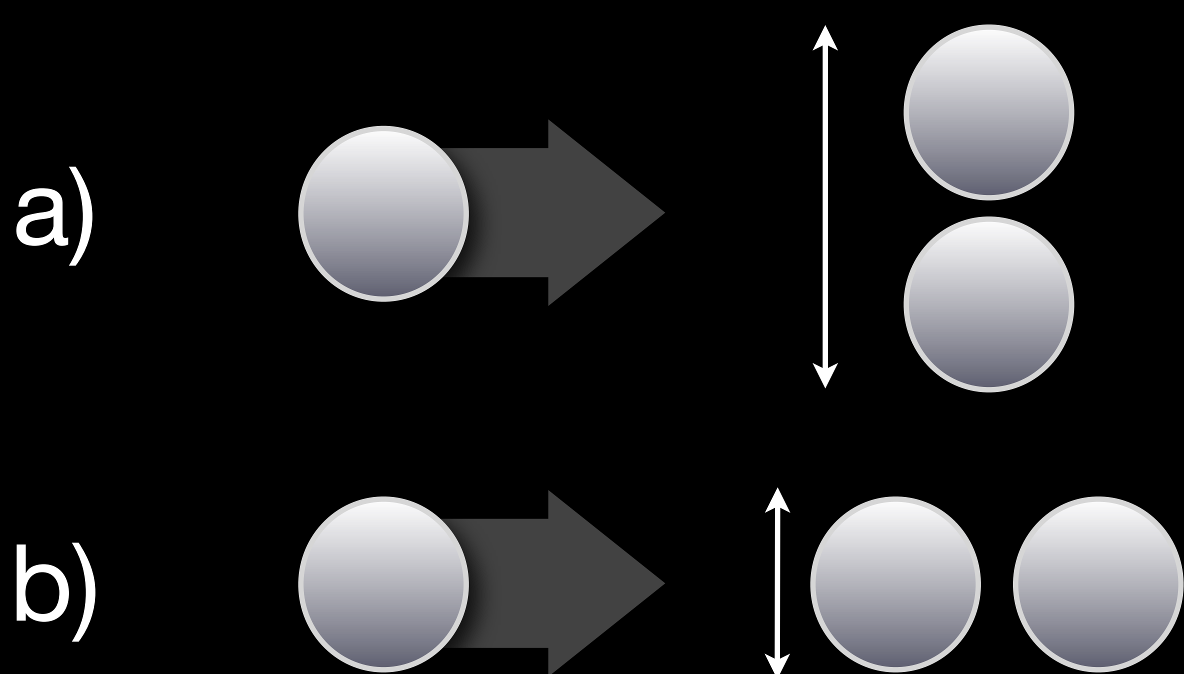
Cross Sections in Deuterium at High Energies

R. J. GLAUBER
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts

(Received May 27, 1955)

Recent measurements of nucleon attenuation at 1.4 Bev (where $\lambda\!\!\!^{-} = 0.1\times10^{-13}$ cm) seem, on the contrary, to reveal a substantial lack of additivity of the neutron and proton cross sections, in deuterium.[1,2] Measurements with incident protons and incident neutrons both indicate that the deuteron cross section is less than the sum of the free-particle cross sections. The measured differences, although obviously subject to uncertainty, amount to 9 mb and 6 mb respectively, values to be compared with $\sigma(n,p)=42$ mb and $\sigma(p,p)=48$ mb.

Some simple considerations may be of help in indicating the nature of the effect. At these energies the attenuation of the incident amplitude by incoherent processes such as meson production may be schematically represented as due to a certain amount of absorption of the incident wave by the nucleons. Since the incident wavelengths in these cases are evidently much smaller than the ranges of interaction, the nucleons may be thought of as casting fairly well-defined shadows. It is then clear that absorption or scattering by either nucleon is reduced when it enters the shadow of the other. Astronomers have long been familiar with a time-reversed analog of this effect; the decrease in luminosity of binary star systems during eclipses.



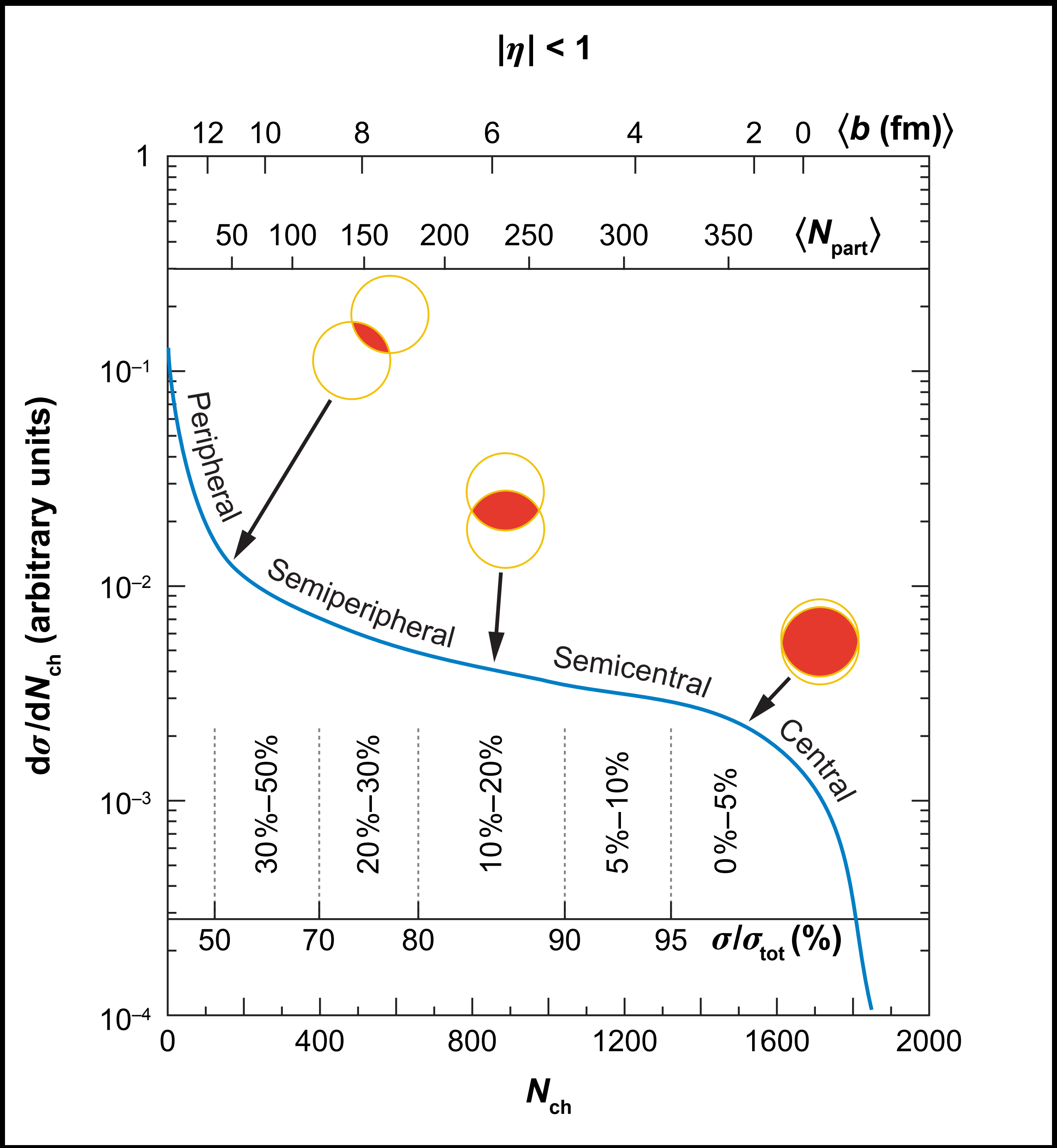
$$\sigma_a > \sigma_b$$

Optical vs. Glauber

- **Not a purely academic question**
- **Nucleon configuration can change event to event, which is how we <u>do</u> physics at RHIC (e.g. v_2)**
- **Our techniques for estimating the geometry should accomodate this**

we average measurements, not vice versa!

What Experimentalists do



In each event, measure energy of particle density in η window

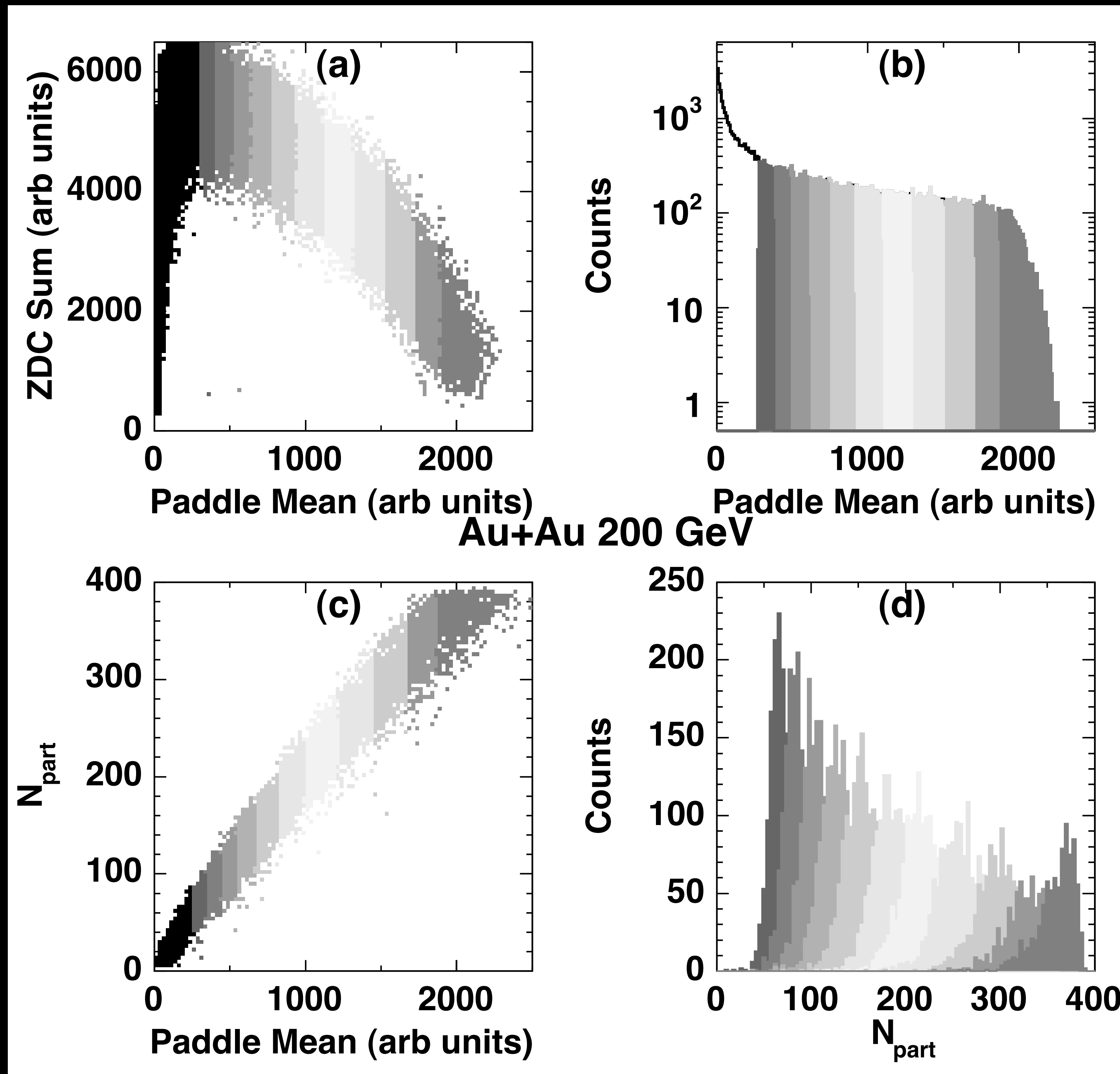
We assume it is monotonic with impact parameter

We incorporate experimental & physics fluctuations (e.g. HIJING/GEANT or NBD)

Then making cuts lets one relate a centrality bin (% of cross section) with a geometric variable

Fluctuations are an essential part of the procedure!

Fluctuations & Centrality



PHOBOS white paper

No experiment measures “clean” centrality bins

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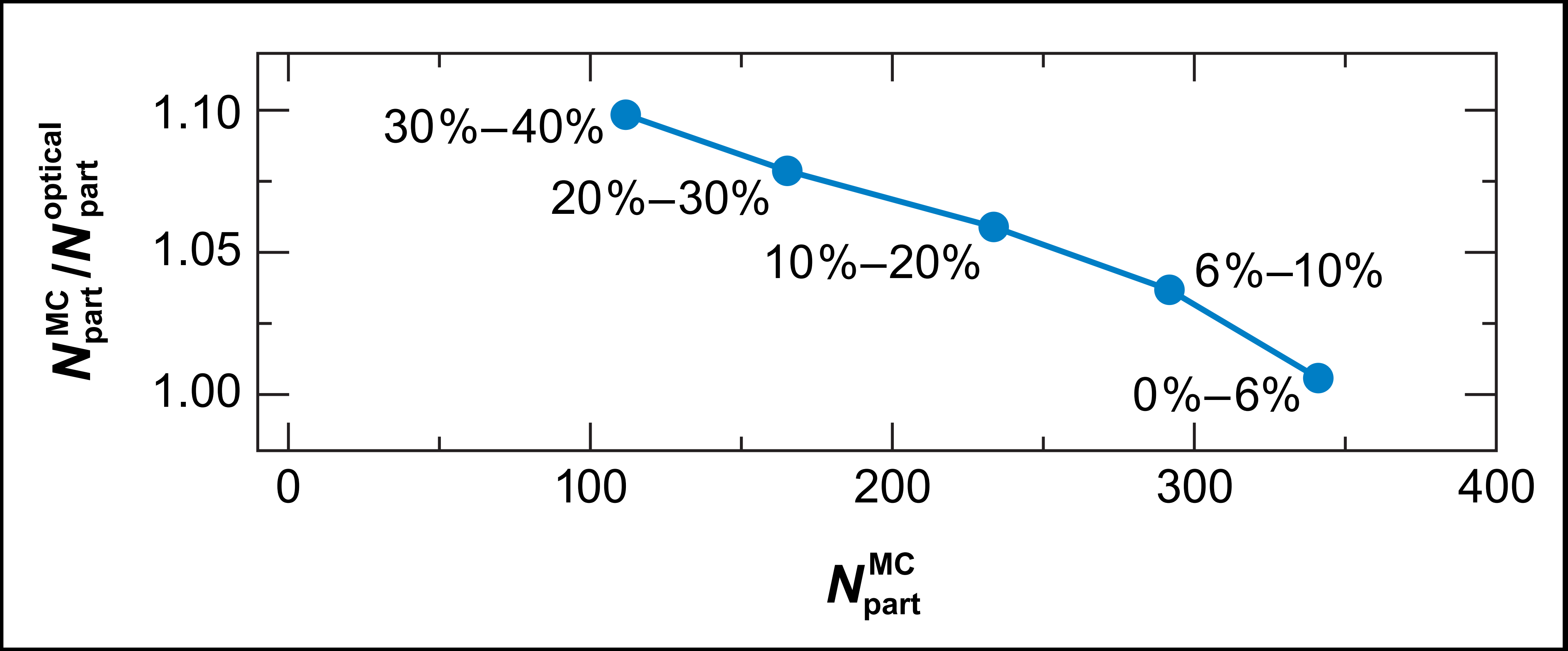
Optical vs. MC



Generically, ignoring fluctuations leads to underestimating N_{part} in peripheral events

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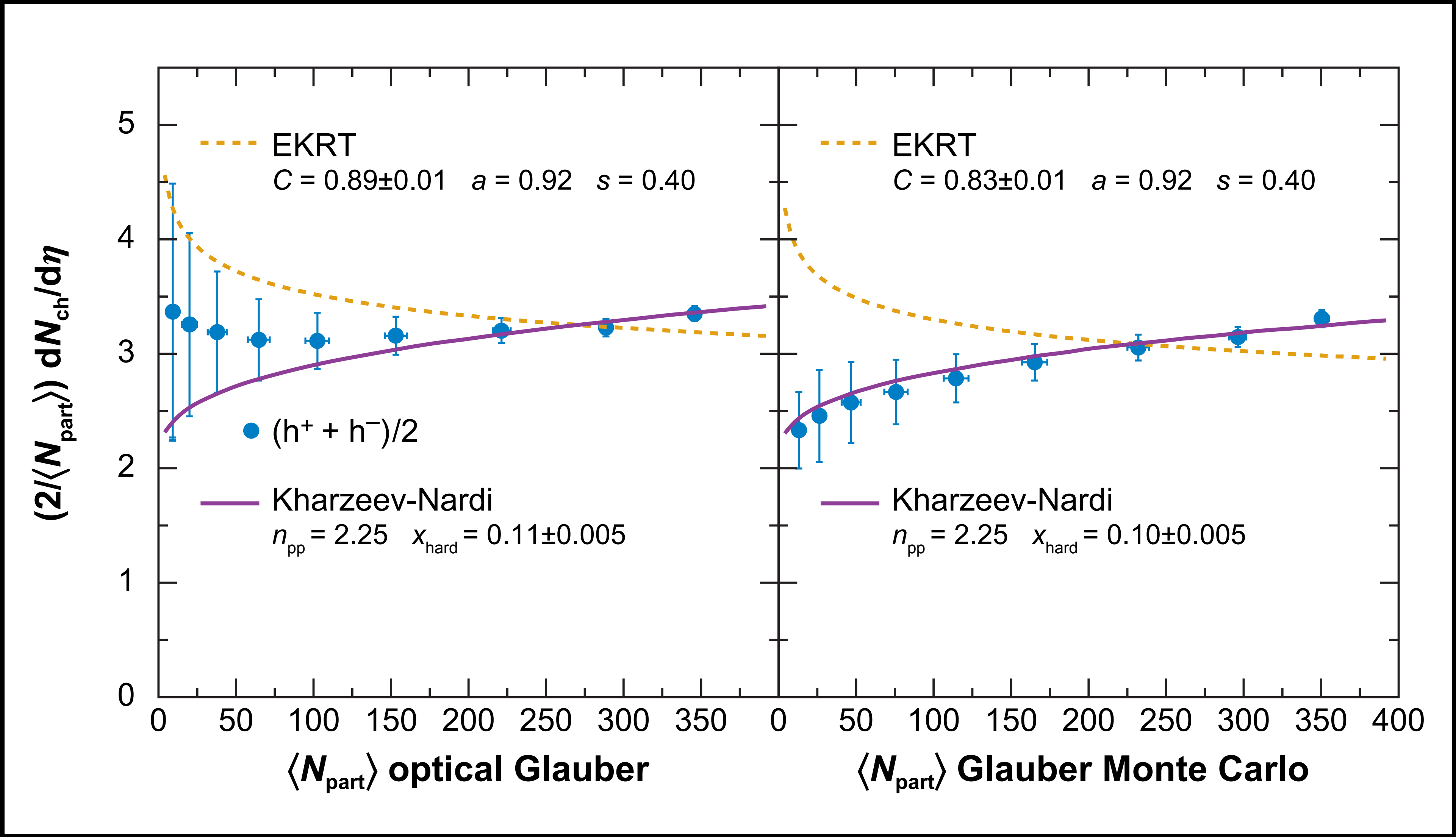
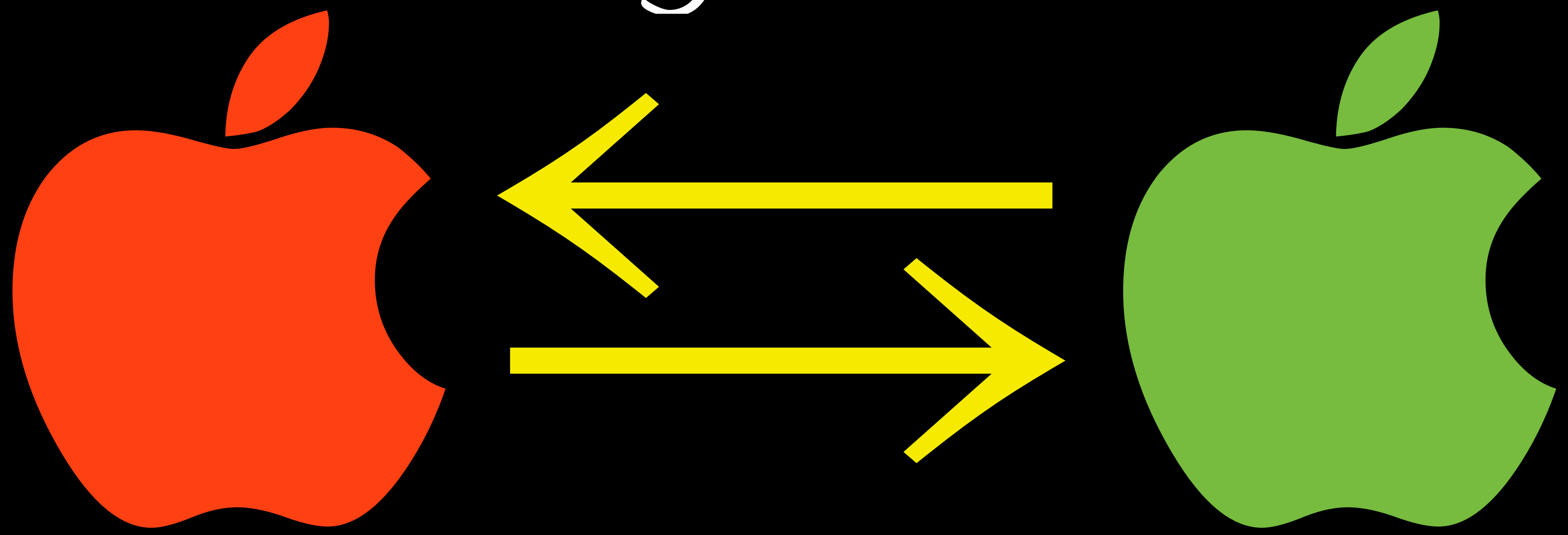
Effect on Observables



Interpretation of data can be changed by using different (i.e. wrong) Glauber approach

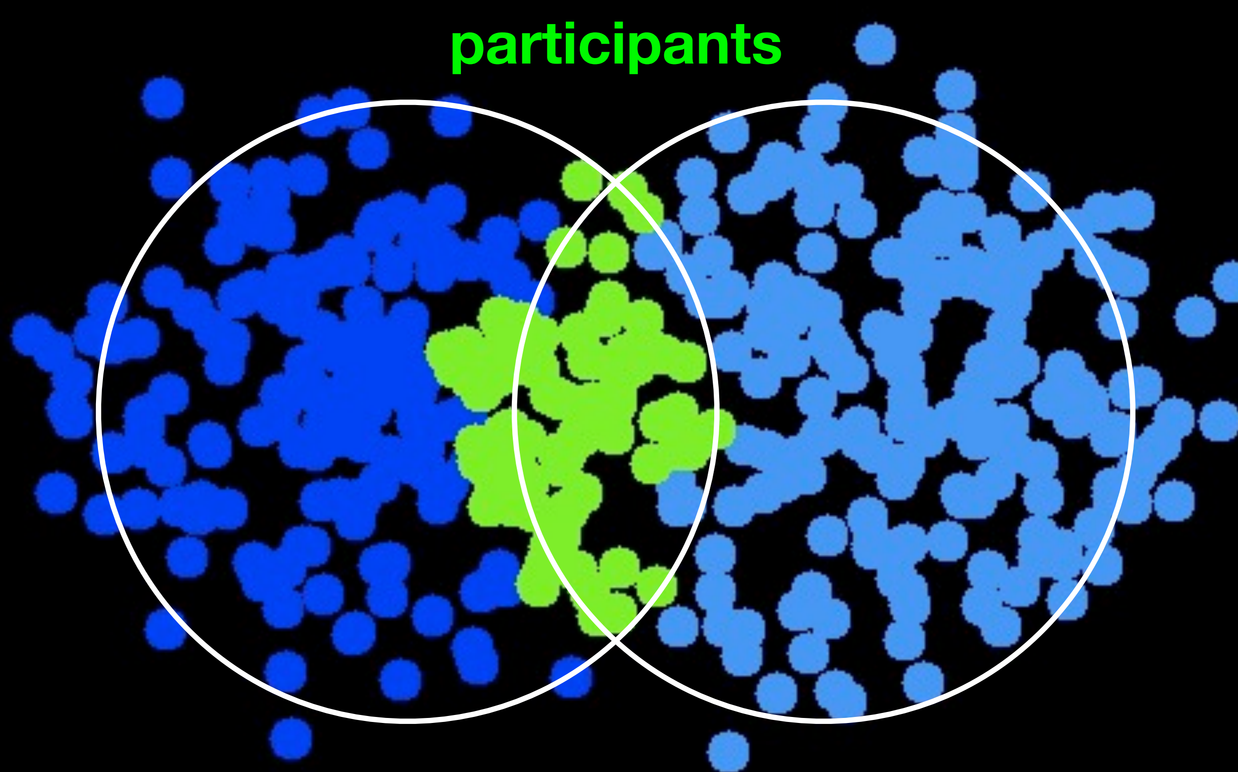
Fluctuating Initial State



Eccentricity Fluctuations

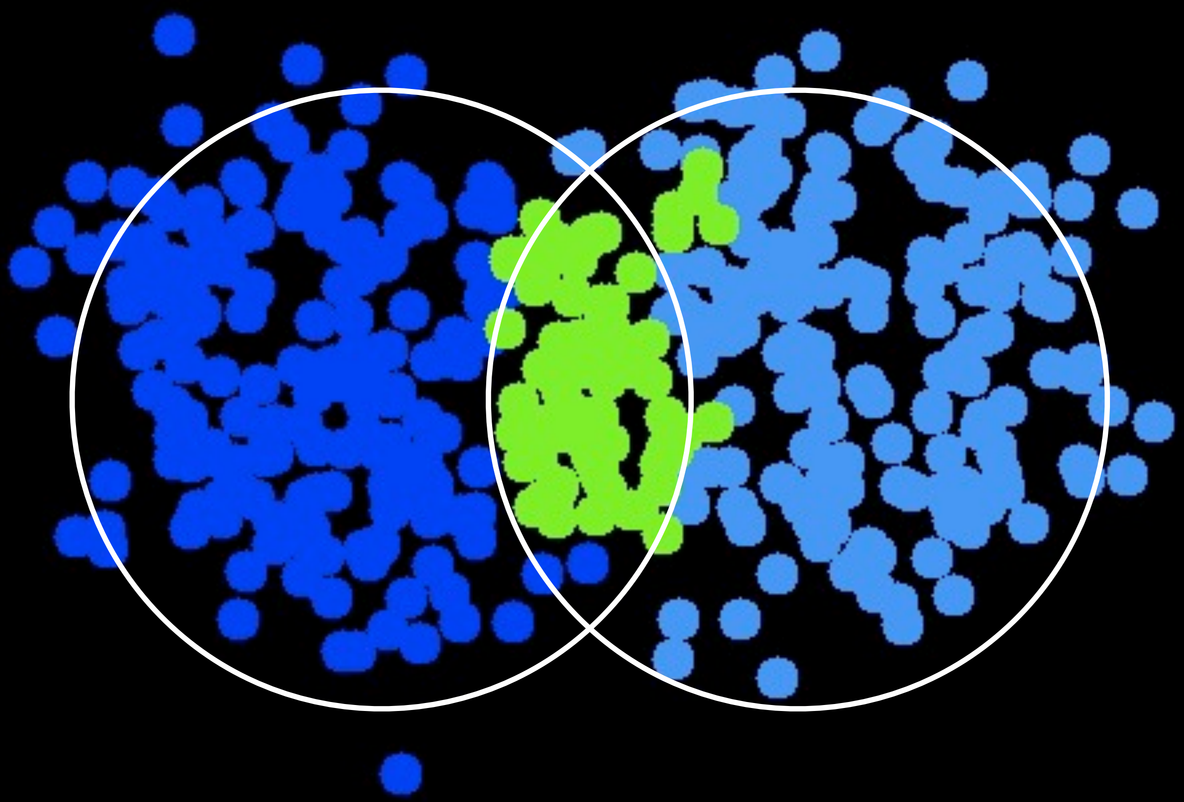
Optical limit

Glauber Monte Carlo

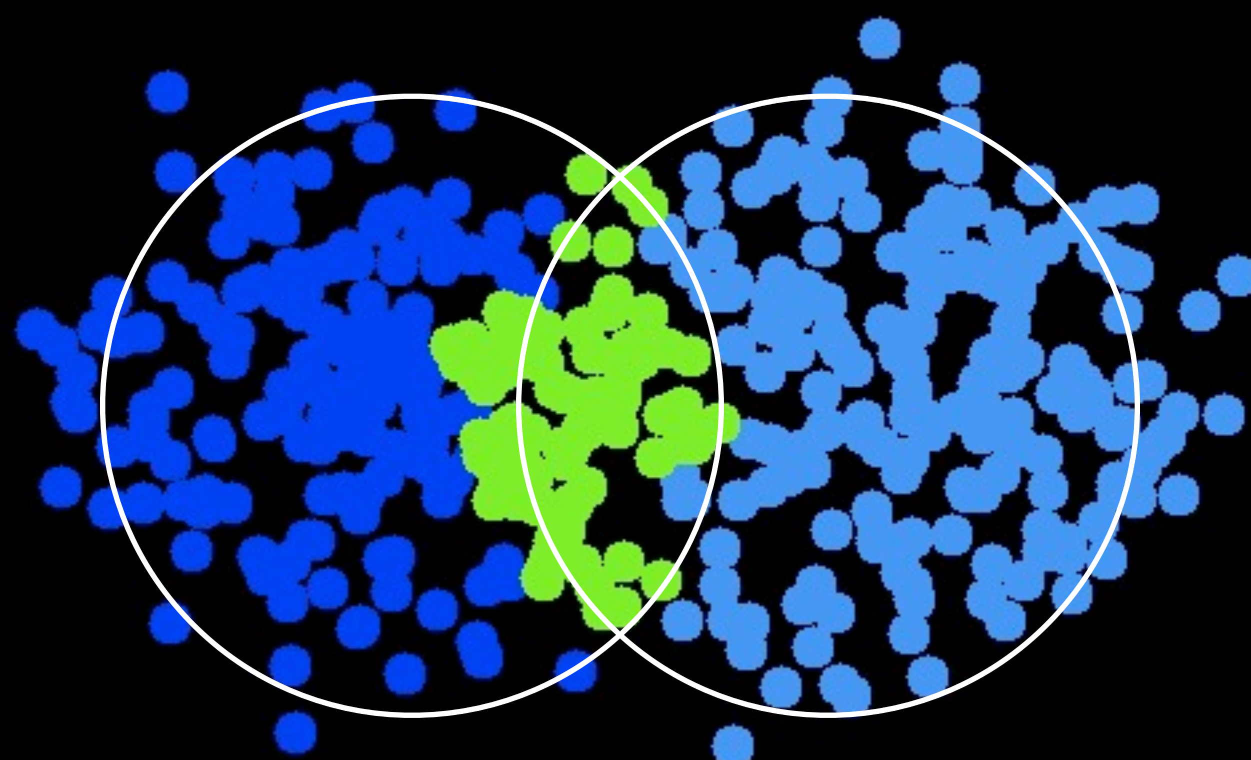


We know nuclei are made of nucleons,
Why “insist” that an <u>average</u> density
matters for flow measurements?

Au+Au



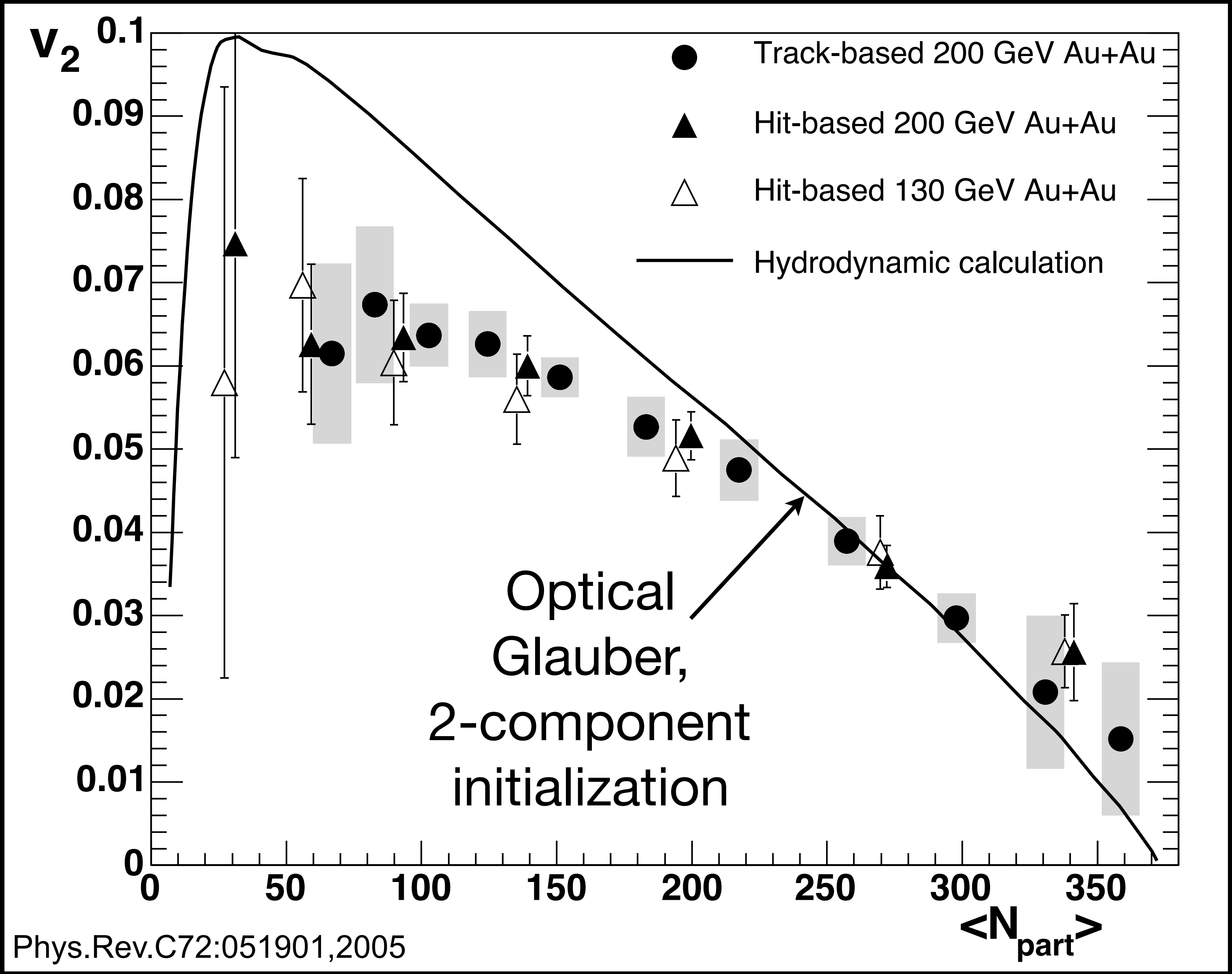
Au+Au



Participants trace out overlap zone, but include
1. Fluctuations (finite number per event)
2. <u>Correlations</u> (it takes two to tango...)

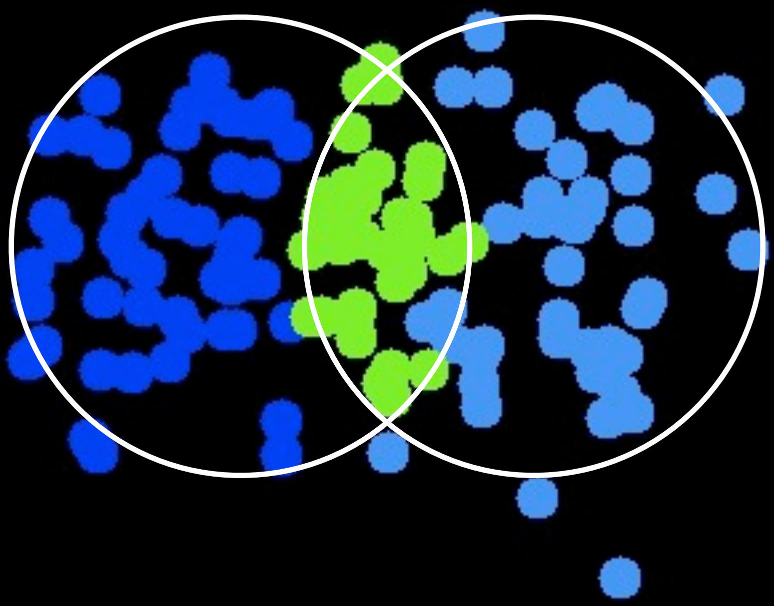
(NB: these are snapshots of nucleon configurations, not stable nuclear states!)

Hydro @ RHIC

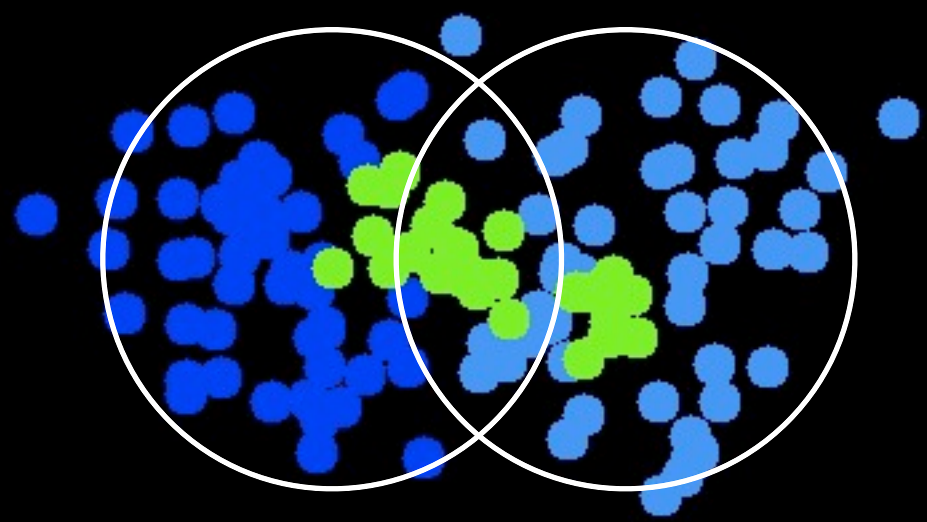


These calculations go down to zero at b=0. The data don't.

Cu+Cu

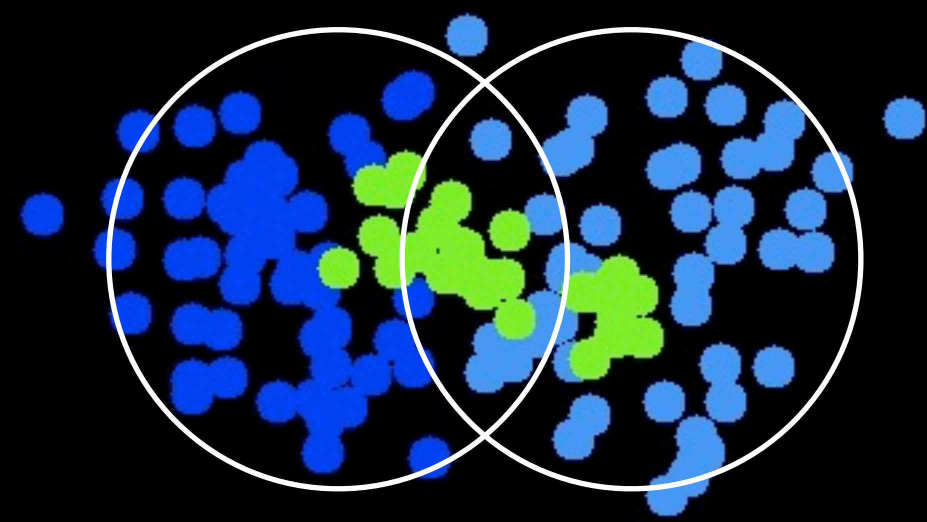


Cu+Cu



Fluctuations can seriously deviate from nominal overlap zone for small numbers of nucleons

Cu+Cu

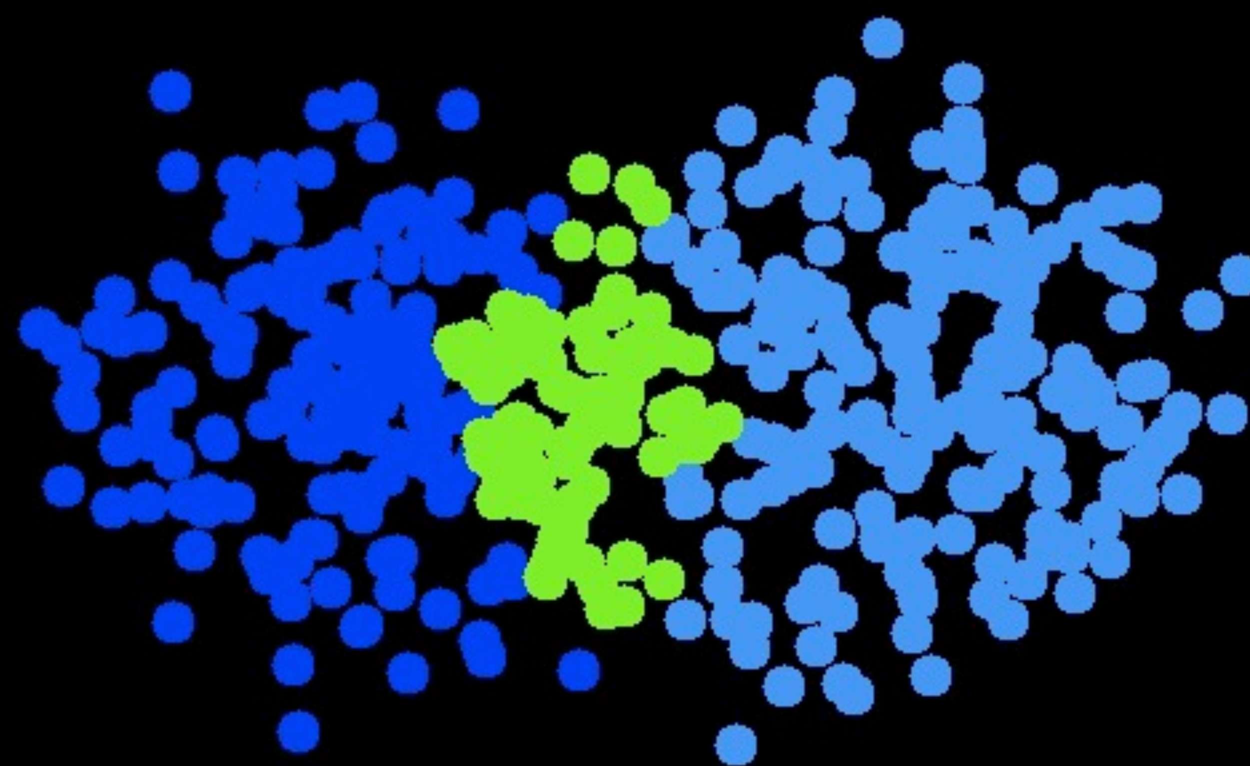


$$\epsilon_{RP} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

similar to "Standard eccentricity" $\epsilon_{std} = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$

SLP ("SPLAT") Approach

Sudden Localized Participant Approach

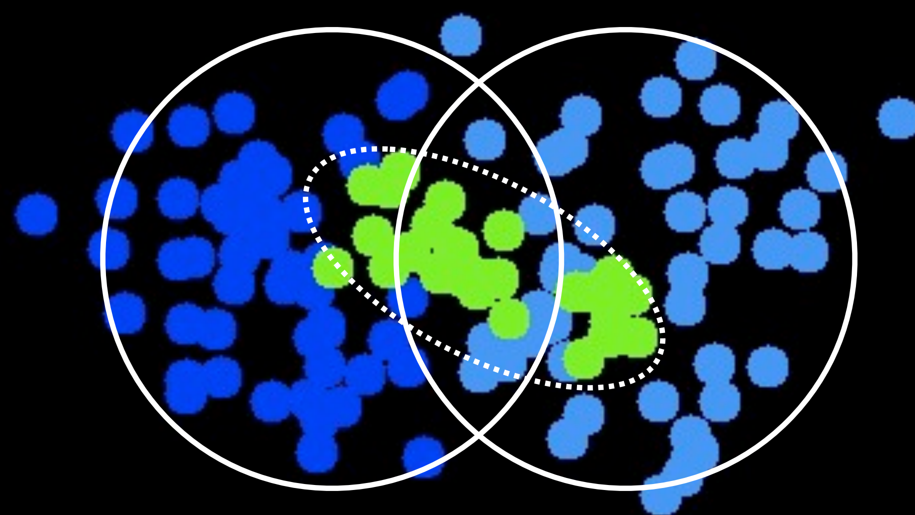


If total entropy is linear with N_{part},
let us also assume that the matter is created
<u>where</u> the soft interactions occur.

If it thermalizes <u>suddenly</u>, then this is the initial state
for hydrodynamic evolution

Cu+Cu

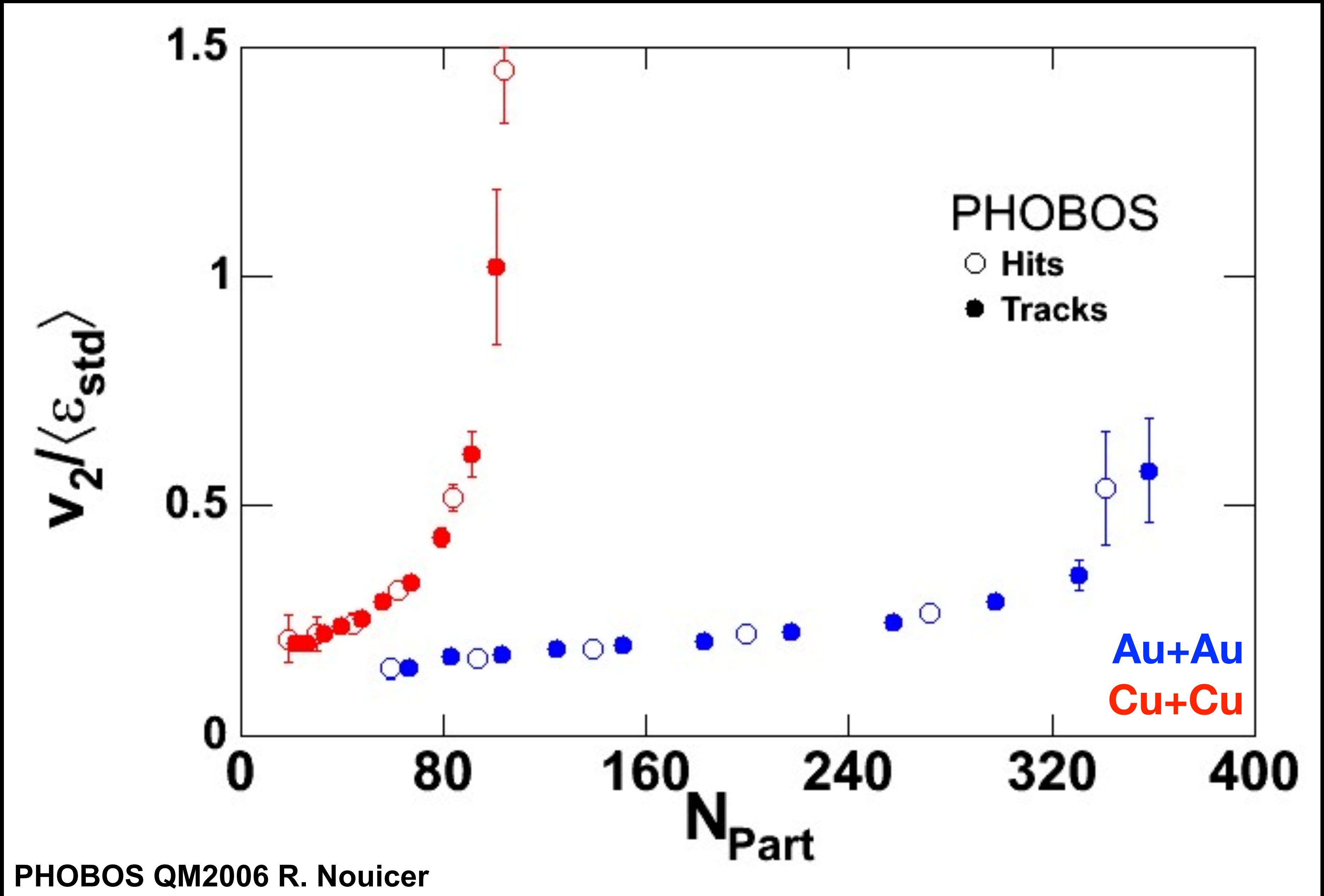
Principal axes make sense if v_2 depends on shape of produced matter (in SLP), not the reaction plane



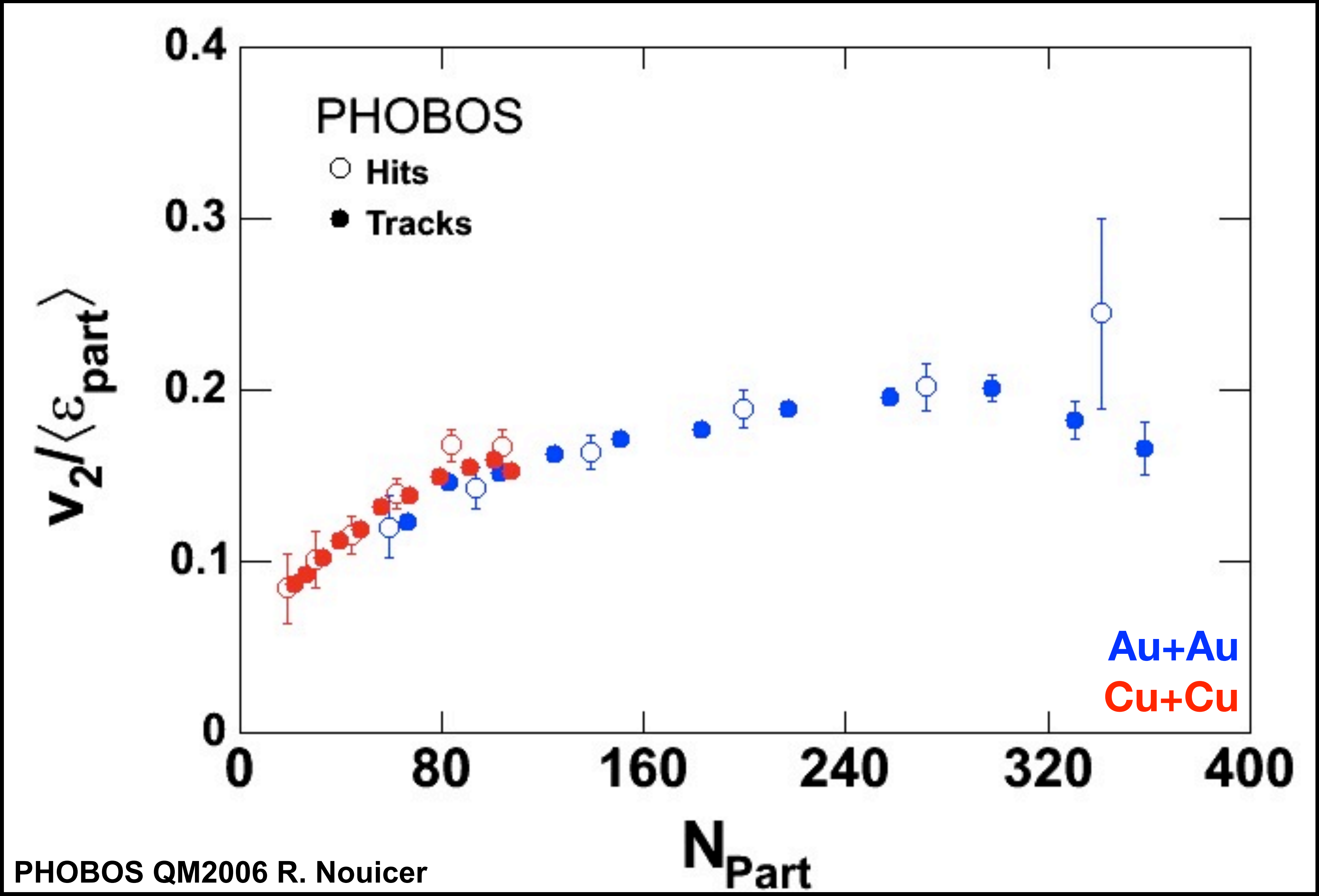
$$\epsilon_{part} = \frac{\sigma_y'^2 - \sigma_x'^2}{\sigma_y'^2 + \sigma_x'^2} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4(\sigma_{xy}^2)^2}}{\sigma_y^2 + \sigma_x^2}$$

"Participant eccentricity"

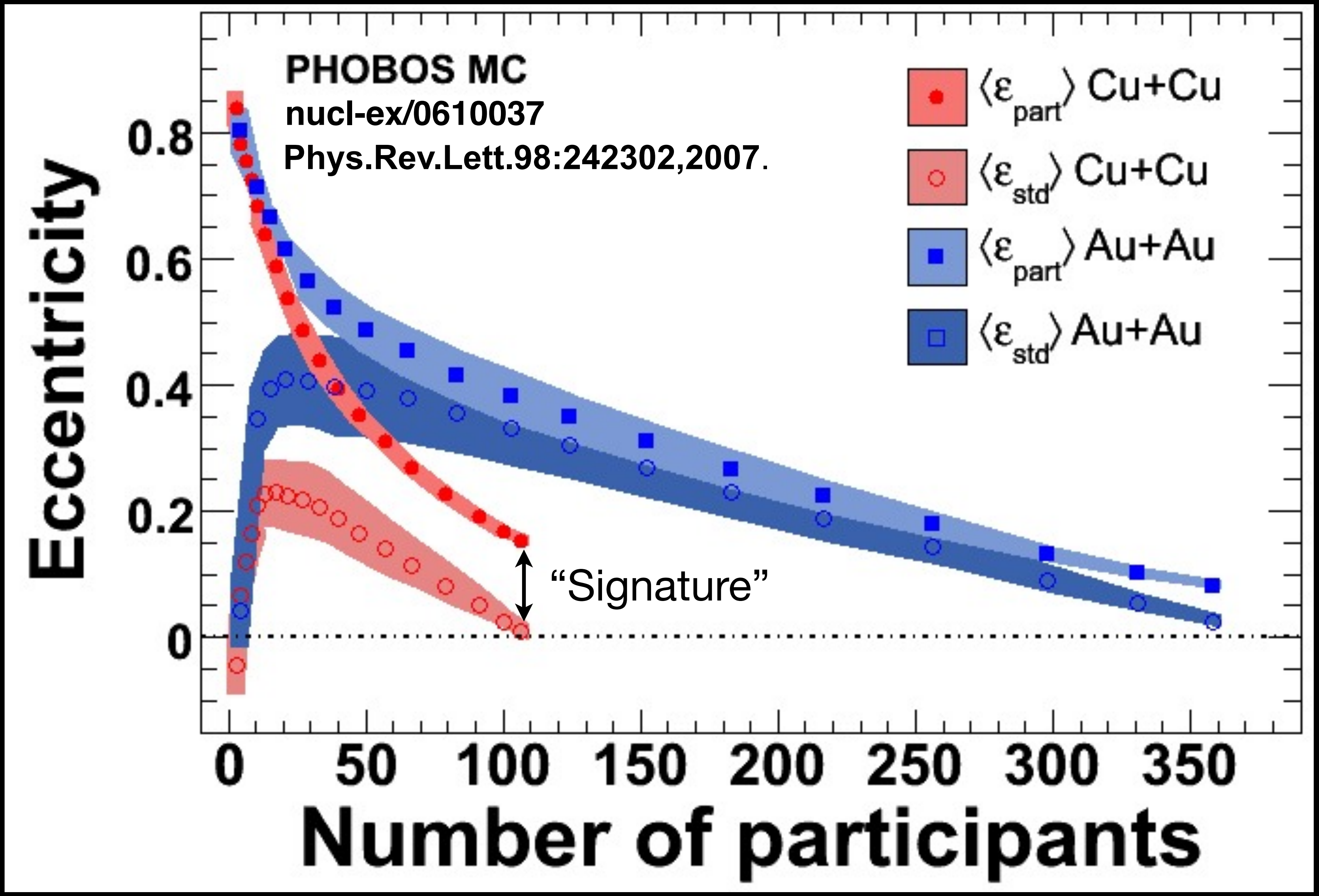
Something disastrous...



...leads to scaling



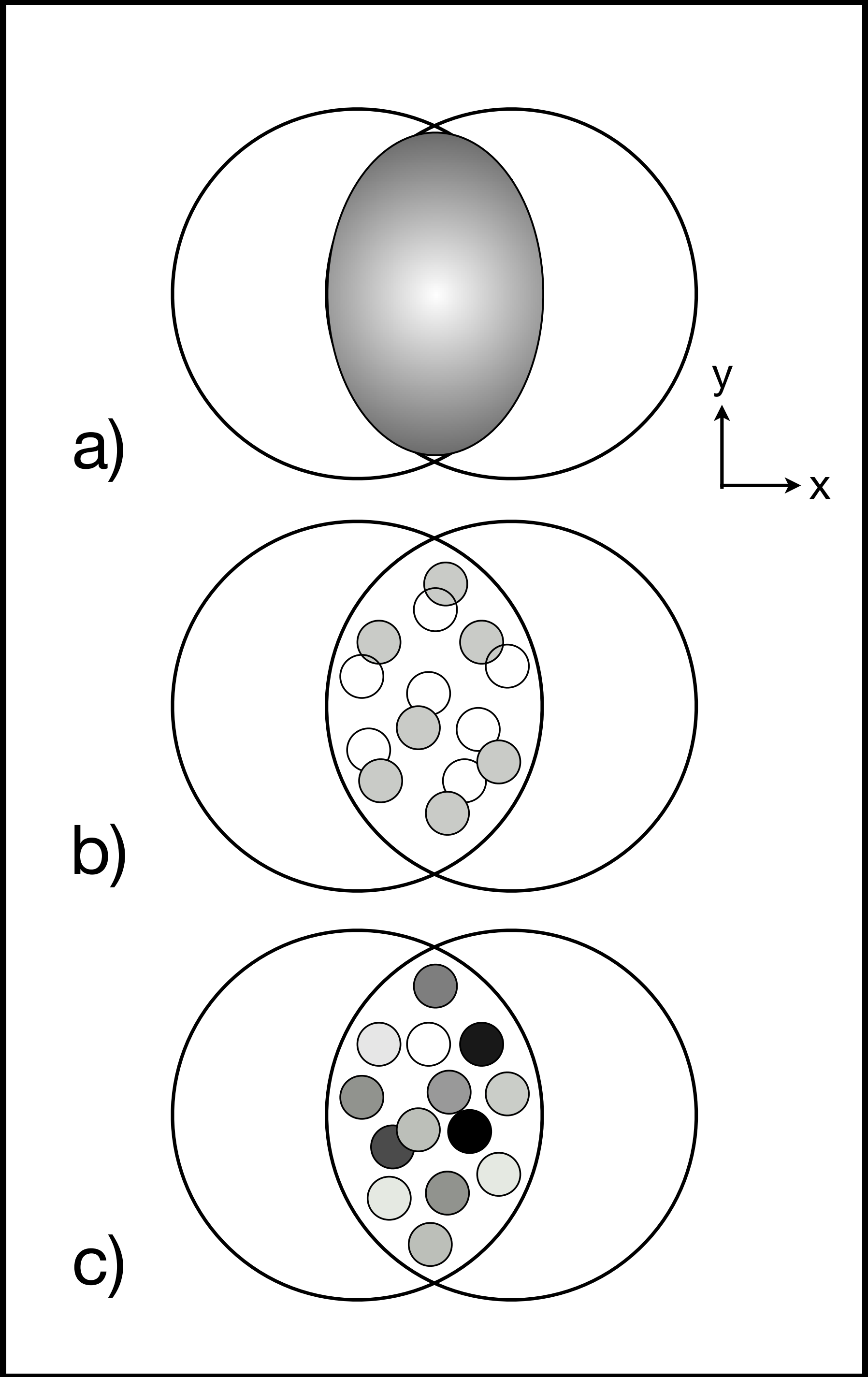
Participant vs. Standard



If you see ε~0 in central collisions, then you are using the wrong eccentricity, or not including fluctuations

Phys. Rev. C **77**, 014906 (2008)

Correlations in A+A Collisions



smooth densities
(leading to “standard” eccentricity)

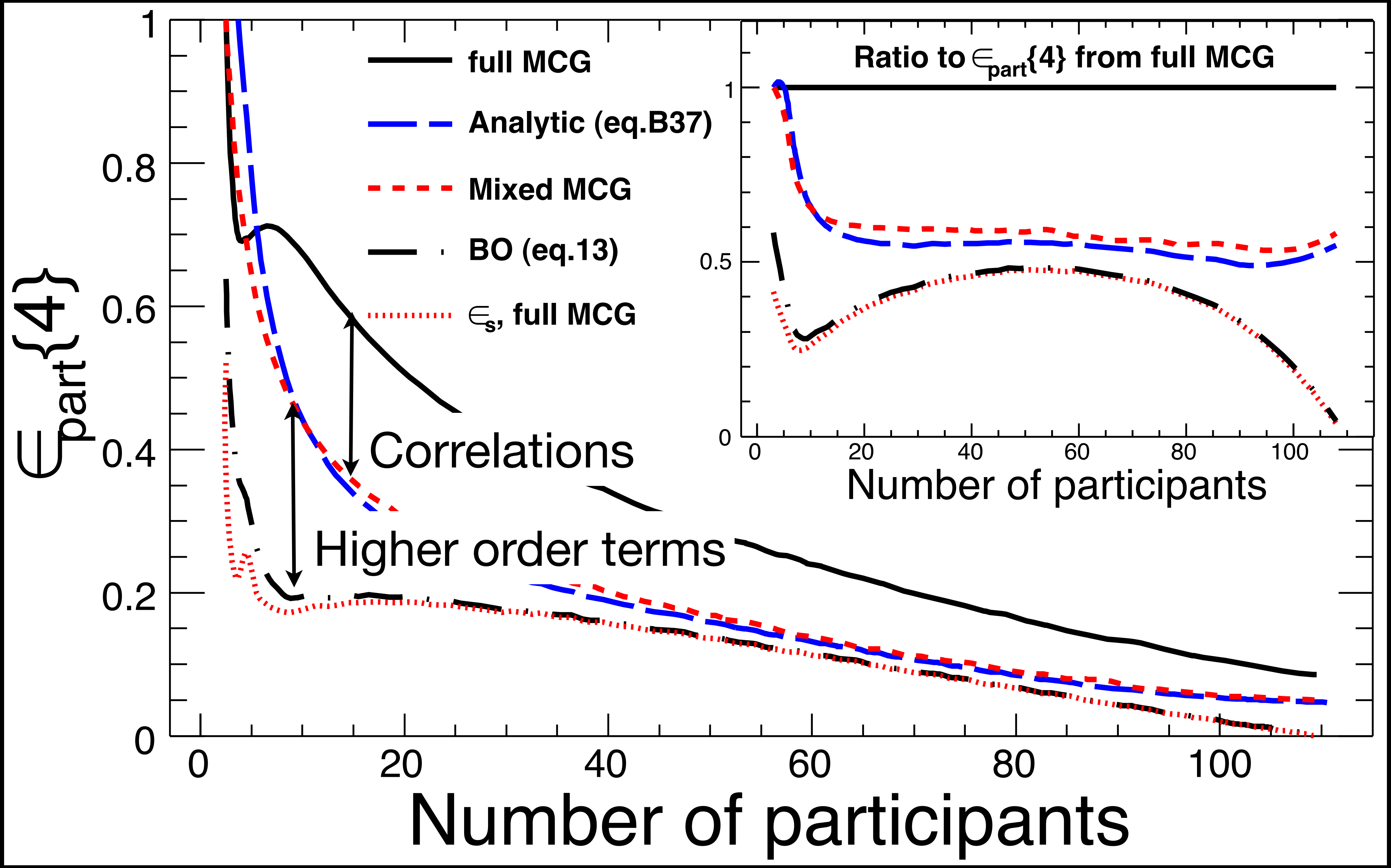
standard Glauber MC
(nucleons collide in pairs,
fluctuations & correlations)

“mixed” Glauber MC
(sample nucleons from
different collisions,
fluctuations & ~~correlations~~)

NB: no correlations between nucleons in a nucleus

Phys. Rev. C **77**, 014906 (2008)

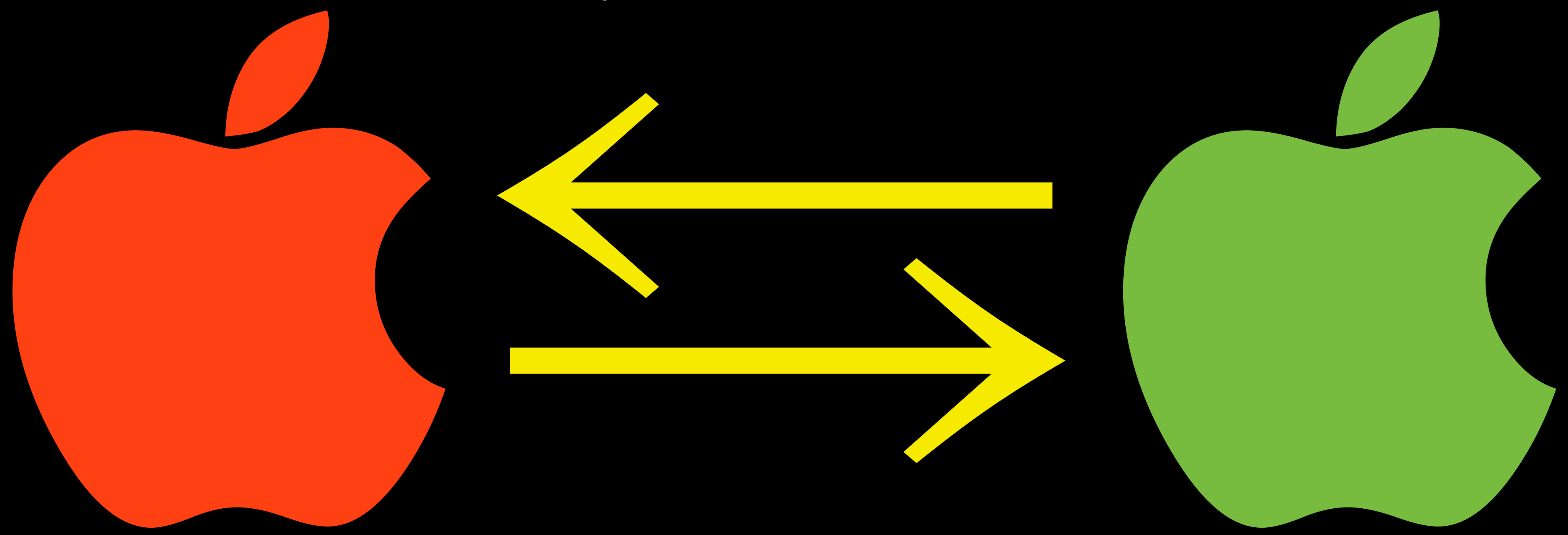
Higher moments



Using cumulants (e.g. ε{2} for 2-particle observables)
to get back to ε_s <u>does</u> <u>not</u> <u>work</u> (B&O truncated expansion too soon)

If this is not clarified, lots of papers will contradict each other!

Two component models



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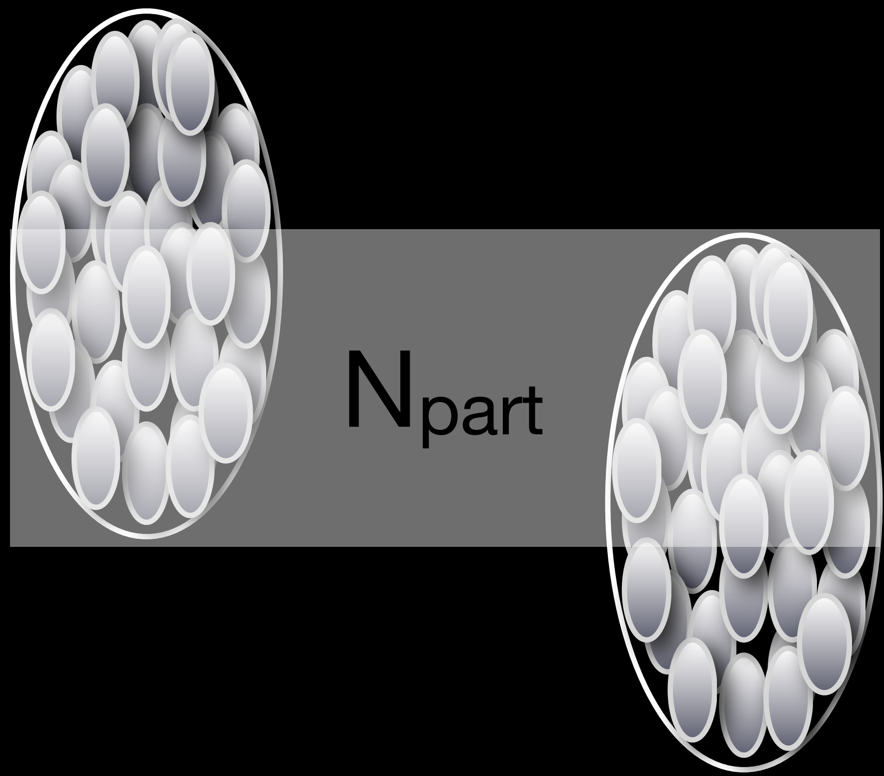
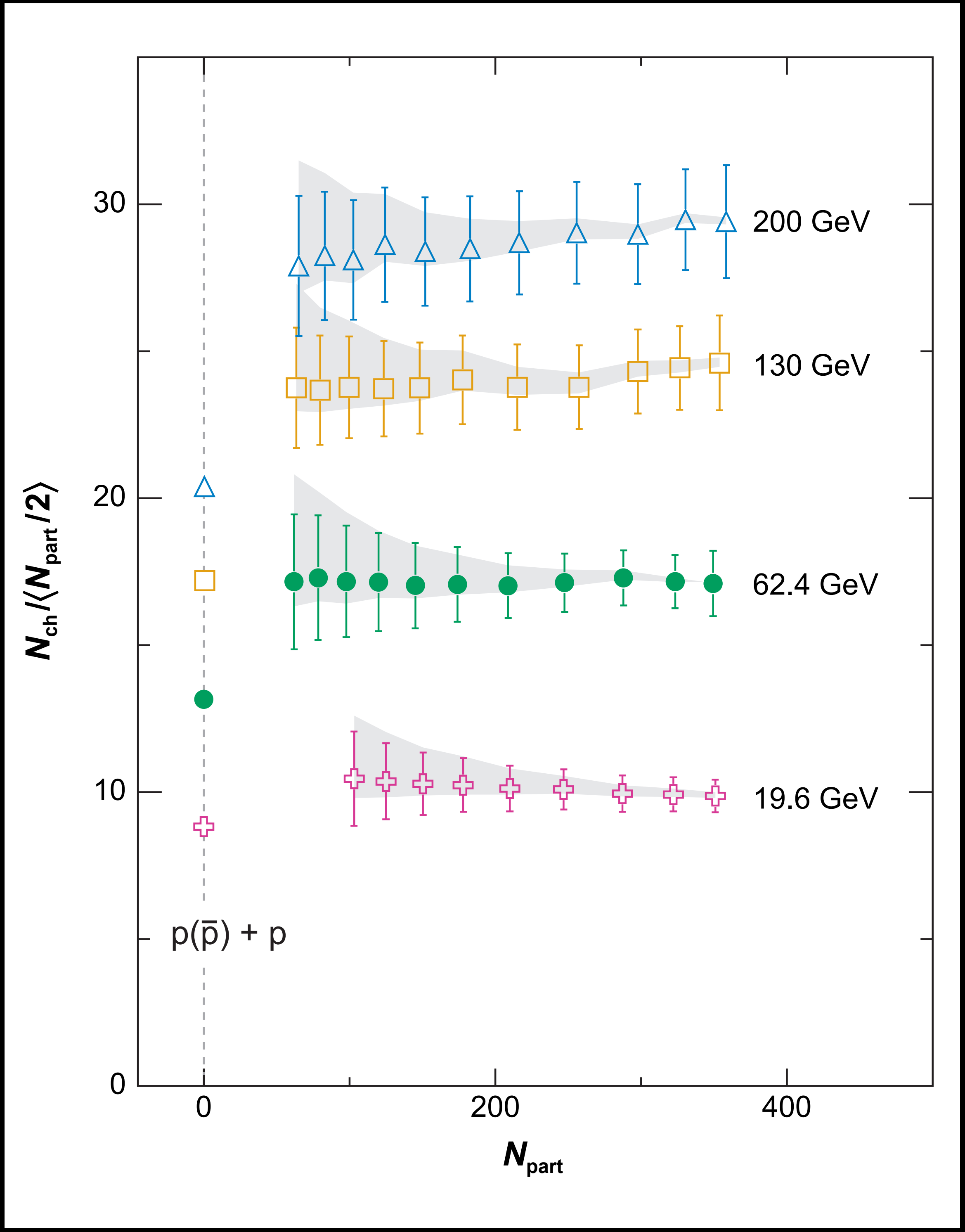
Total Multiplicity



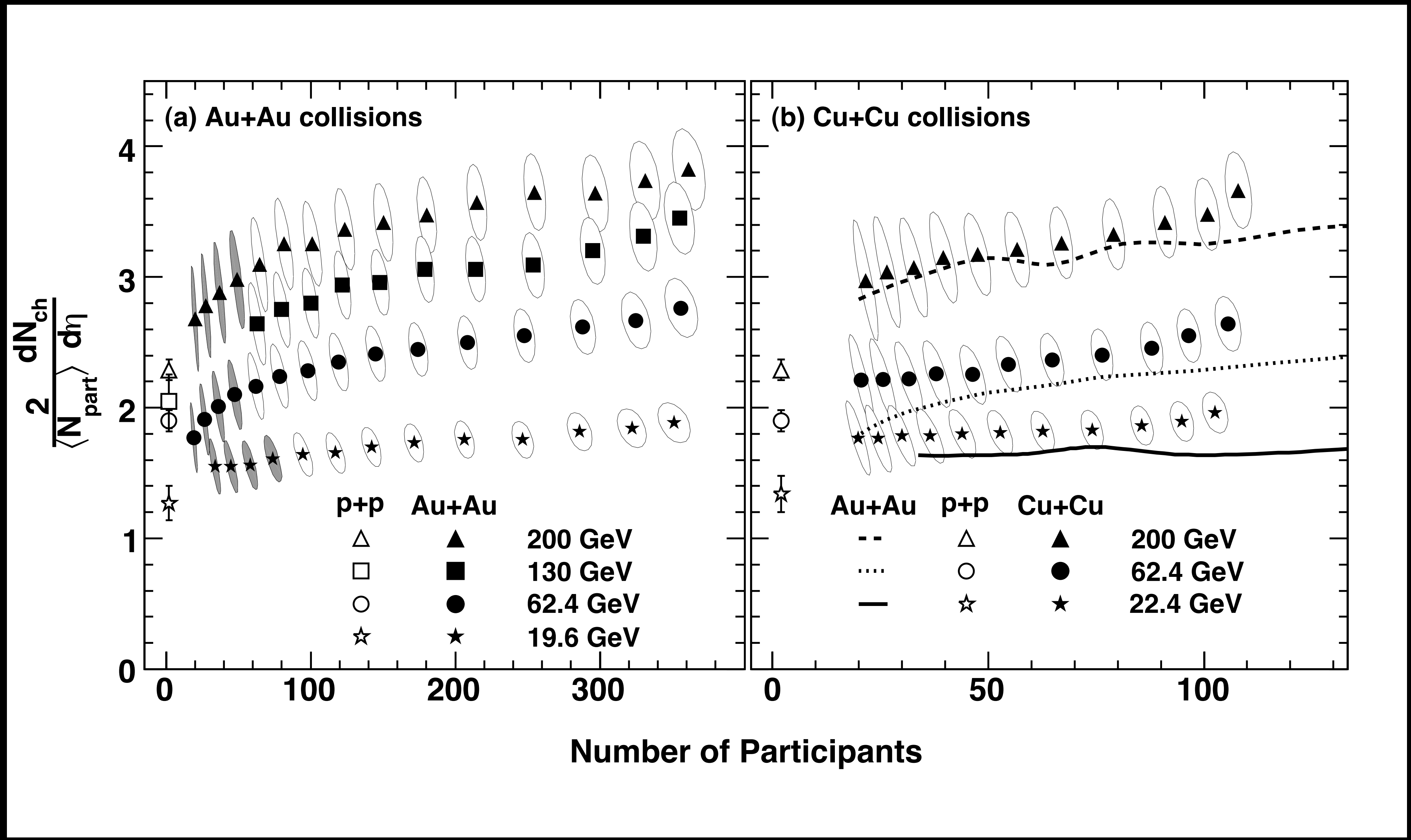
Total particle production
($\propto$ total entropy)
scales <u>linearly</u> with N_{part}

Who needs two components?

Phys.Rev.C74:021902,2006



Multiplicity @ mid-rapidity

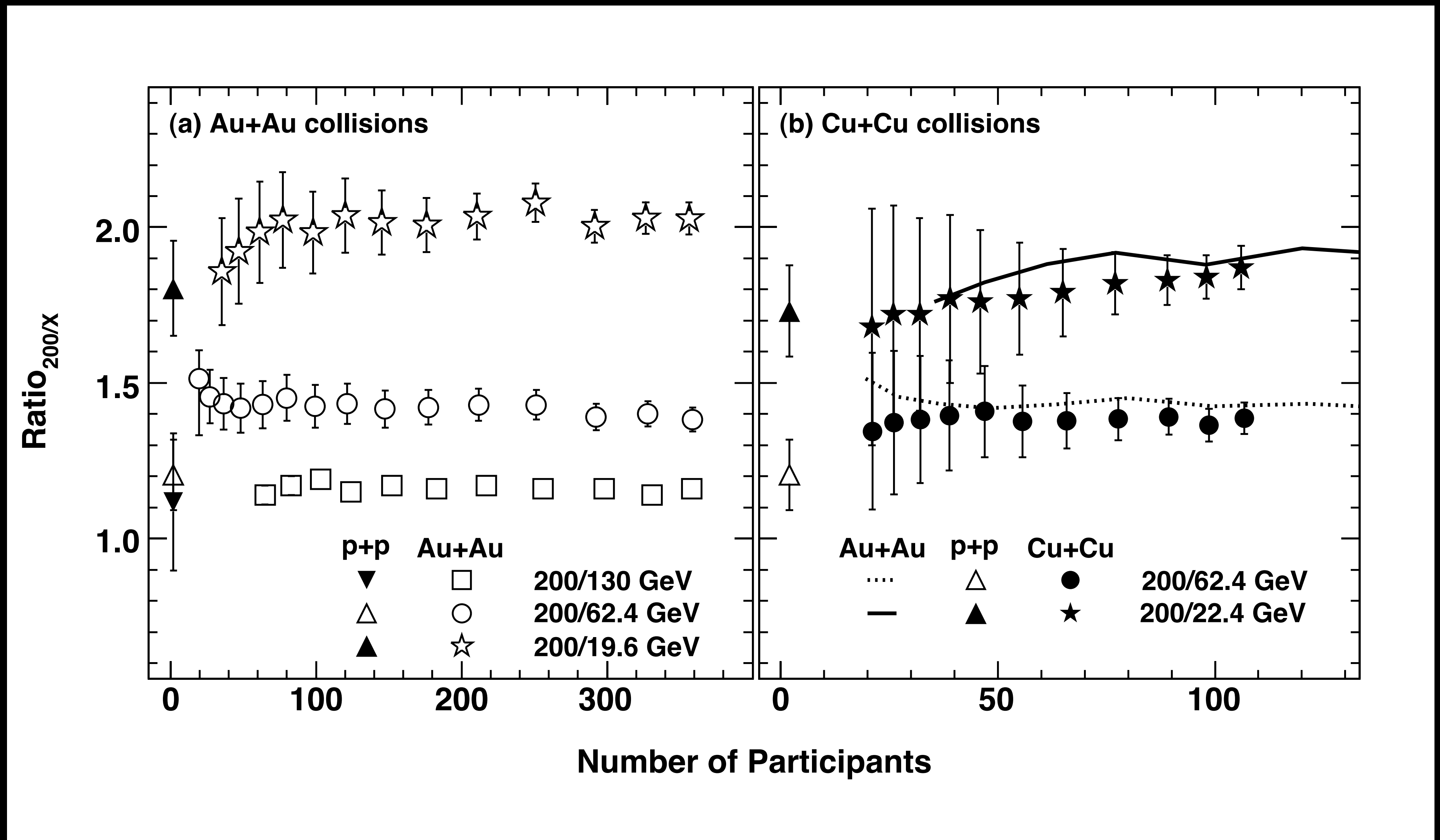


And yet, we all know that things look very different at mid-rapidity: not at all linear with N_{part}

"Two-component model" (Kharzeev & Nardi)

$$\frac{dN}{d\eta} = n_{pp}\left\{(1-x)\frac{N_{part}}{2} + xN_{coll}\right\}$$

Against two components



Centrality dependence does <u>not</u> change with energy
(so interpretation as semi-hard processes doubtful)

x = 0.13±0.01(stat)±0.05(stat) (PHOBOS 2004)

Local 2-component model

- **Several ways to parametrize the two component models in hydro models**
  - KLN $$\frac{dS}{d^2x_\perp} \propto \left[(1-x)\frac{1}{2}\frac{dN_{part}}{d^2x_\perp} + x\frac{dN_{coll}}{d^2x_\perp}\right]$$
  - Hirano et al (2005) $$\frac{dS}{d^2x_\perp} \propto \left[\alpha\frac{dN_{part}}{d^2x_\perp} + (1-\alpha)\frac{dN_{coll}}{d^2x_\perp}\right]$$
- **The two parametrizations are equivalent** $x = \frac{1-\alpha}{1+\alpha}$
- **Several values floating around the literature**
  - Drescher et al (2006) use “80:20”, i.e. α=0.8, or x=0.11
  - Heinz et al use “85:15”, i.e. α=0.85 or x=0.08
- **Something seems problematic here**
  - Do these all reproduce dN/dη with the same precision?

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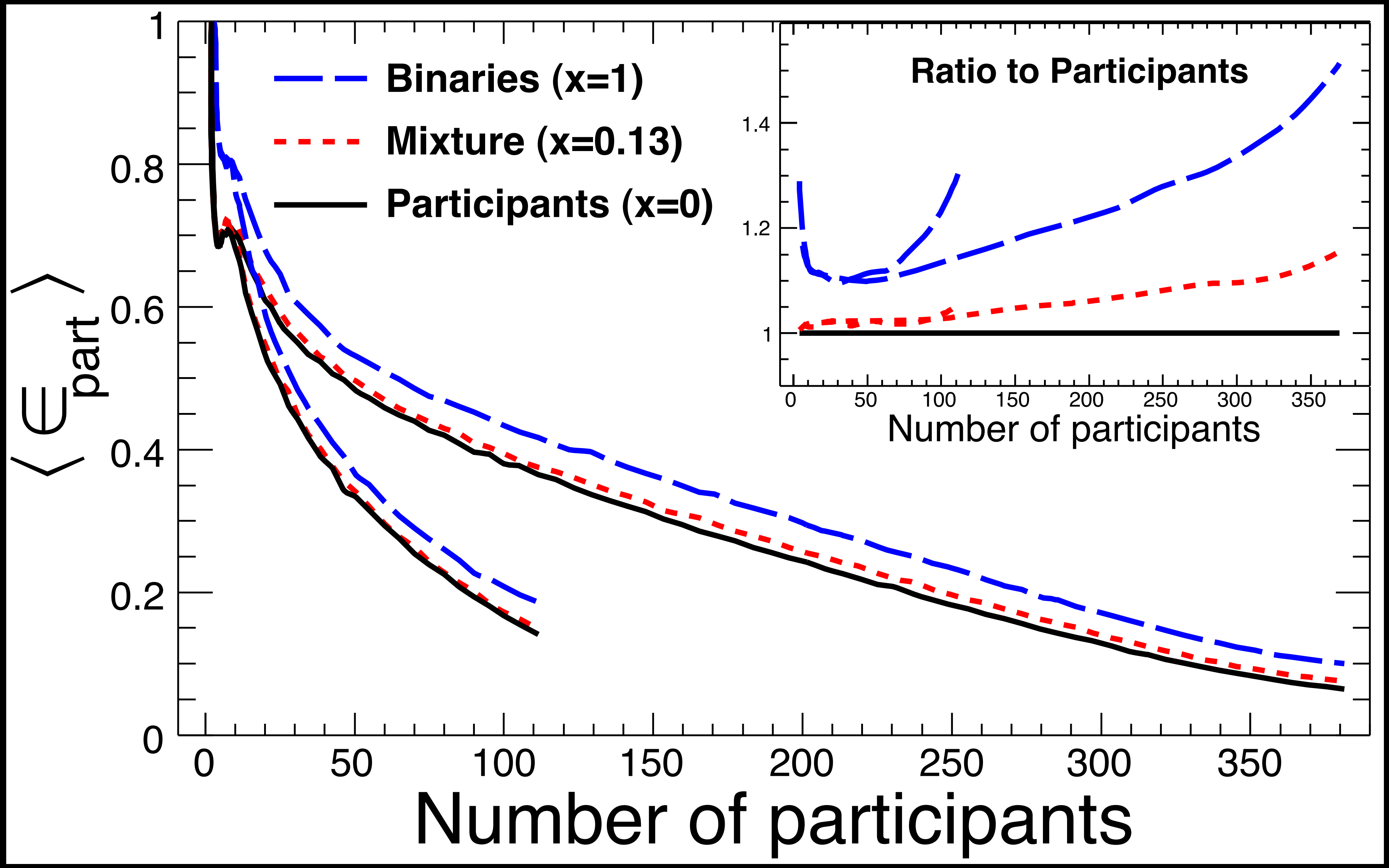
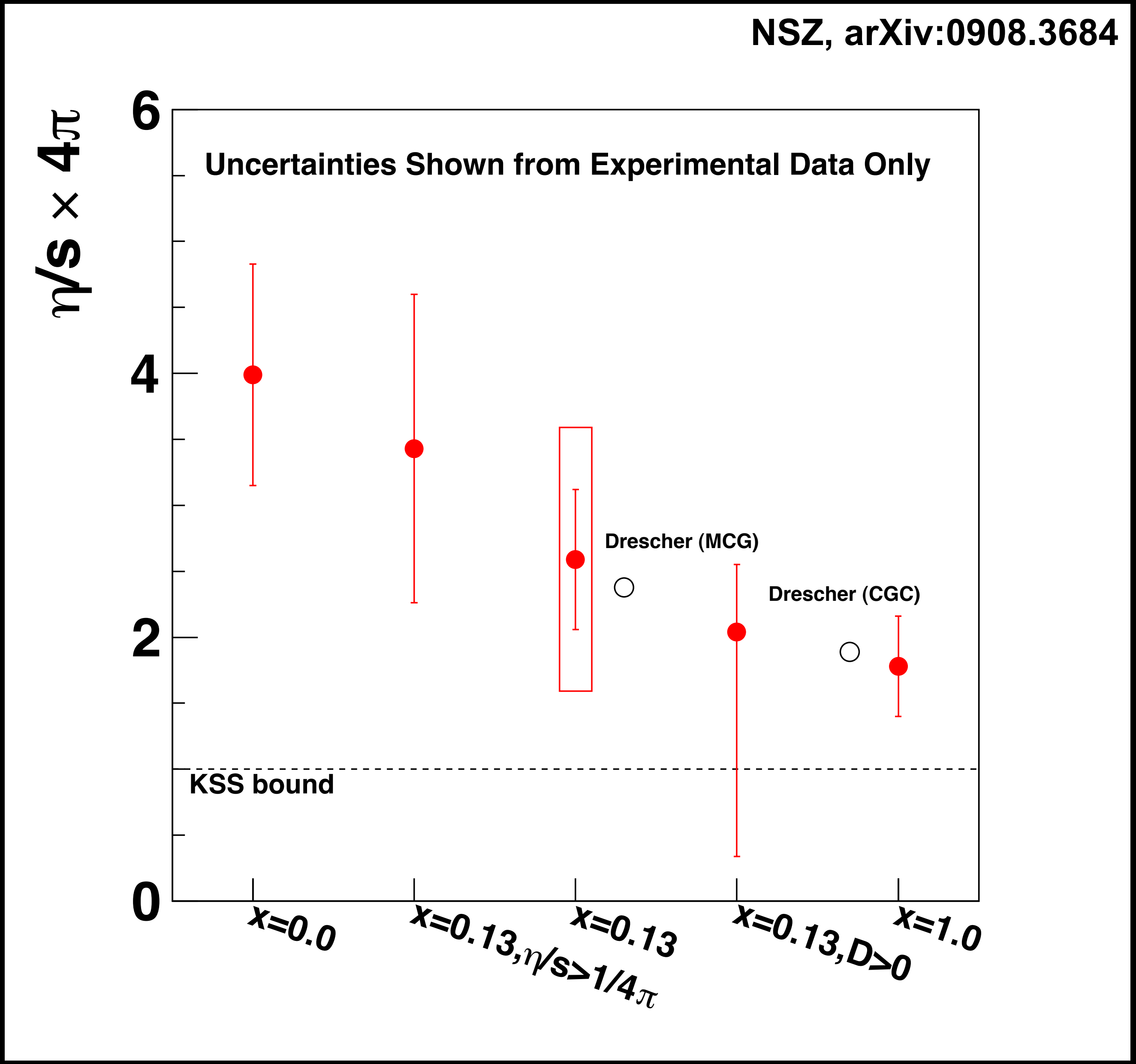
Participants vs. Collisions



Only a 10% effect between peripheral & central with the canonical value of x=0.13

But it can matter!



Nagle, PAS, Zajc: varying the initial conditions for the eccentricity have a strong effect on extracted η/s (using Knudsen number)

A lost thread

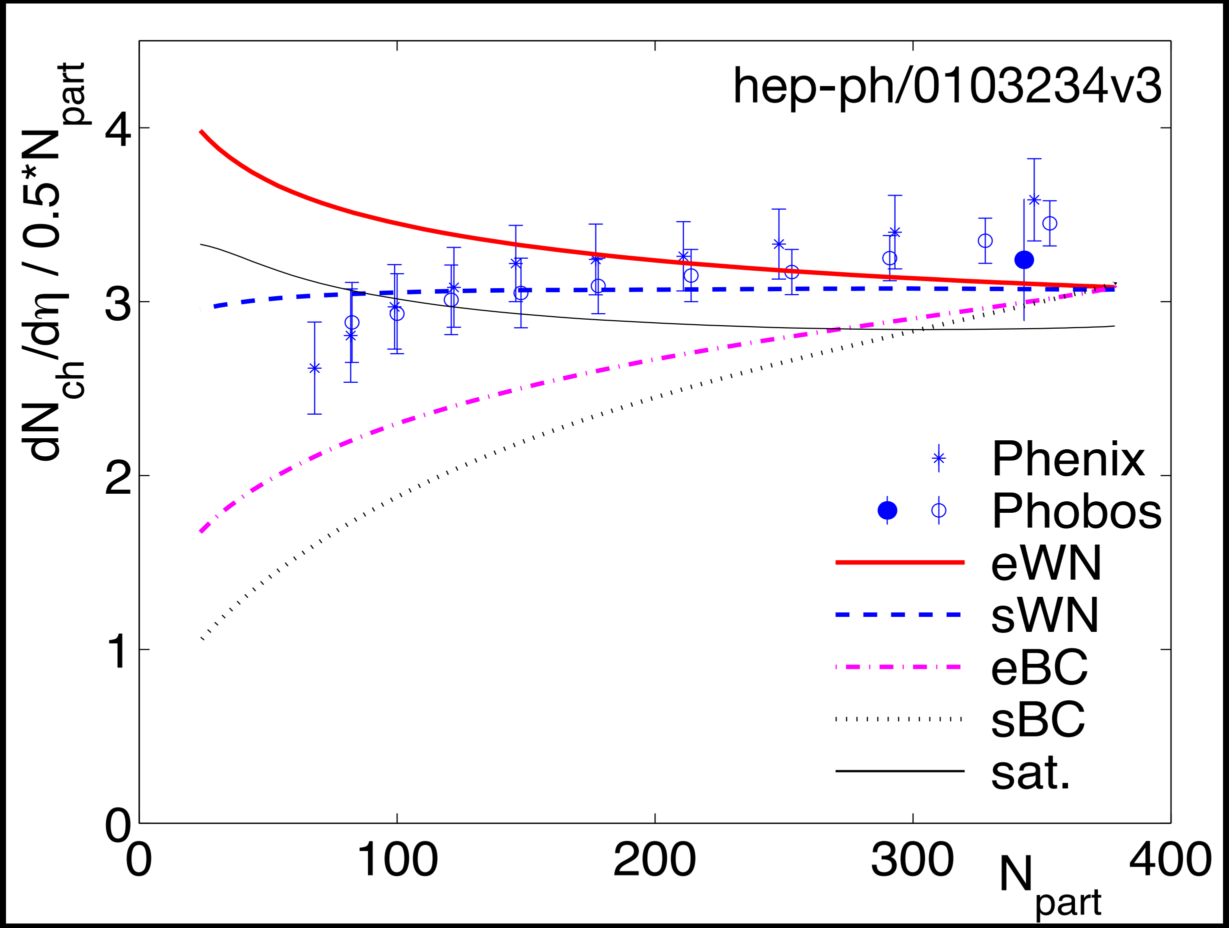
Hydro modelers choose between energy and entropy density (using EOS to map one onto the other, as Pasi reminded me)

$$\epsilon_{WN} \propto \frac{d^3 N_{part}}{dxdydy}$$

$$s_{WN} \propto \frac{d^3 N_{part}}{dxdydy}$$

$$\epsilon_{BC} \propto \frac{d^3 N_{coll}}{dxdydy}$$

$$s_{BC} \propto \frac{d^3 N_{coll}}{dxdydy}$$



$$N_{coll} \propto N_{part}^{4/3}$$

$$\epsilon \propto s^{4/3}$$

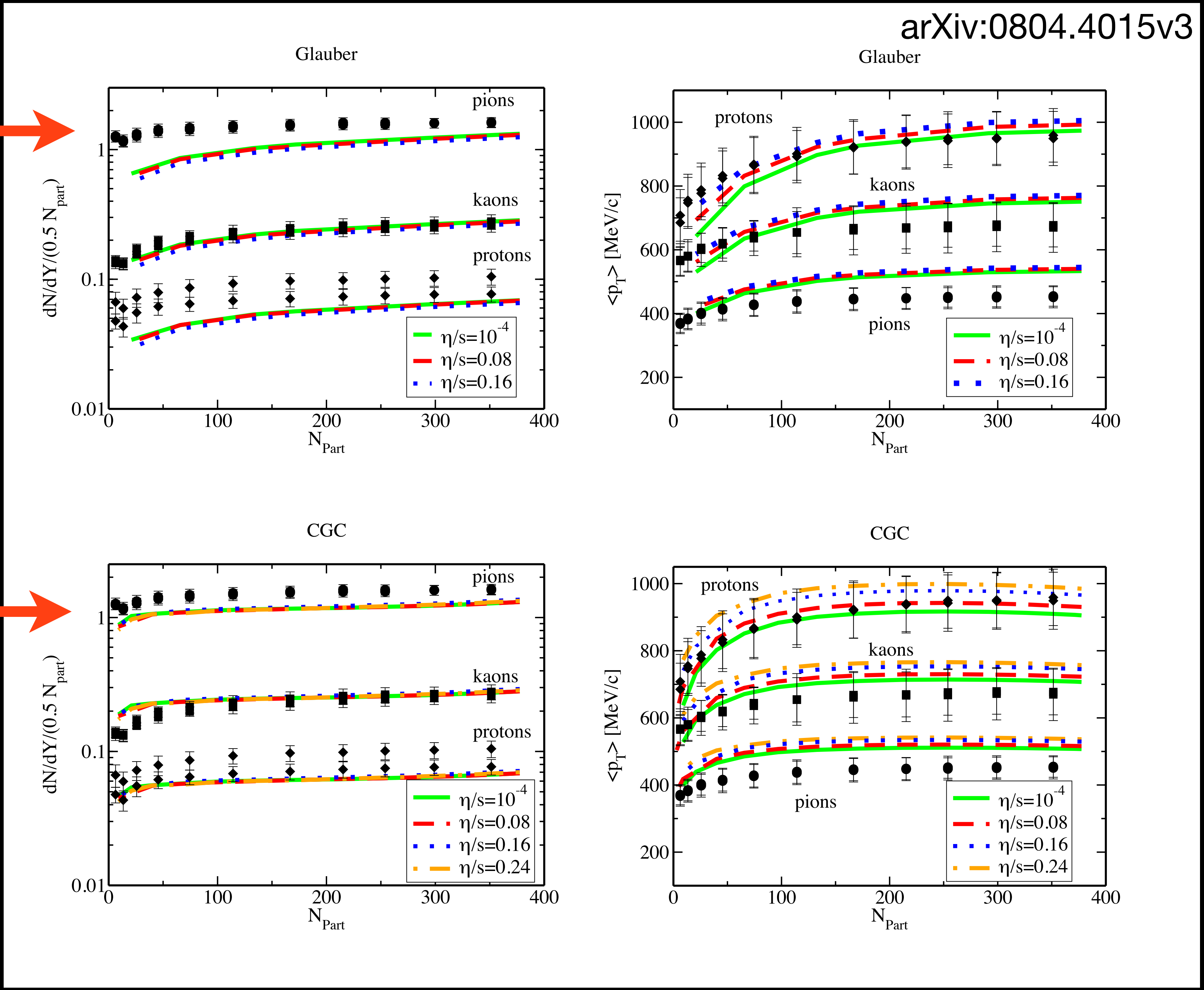
$$\Rightarrow \quad s_{WN} \overset{?}{\sim} \epsilon_{BC}$$

Why would you choose ε_{BC} vs. two-component?

Check the details!

ahem

ahem



Romatschke & Luzum do choose ε_{BC}...and maybe they shouldn't?

MC-KLN

MC-KLN is a tricky case:

in some formulations it's just ε_{BC} (Lappi & Venugopalan)

but in general it tends to "throw out" nucleons

And in particular there are implementations that literally throw out nucleons that are "too far" from each other

But if you "fix" MC-KLN, fix the Glauber similarly!

Drescher & Nara, arXiv:0707.0249

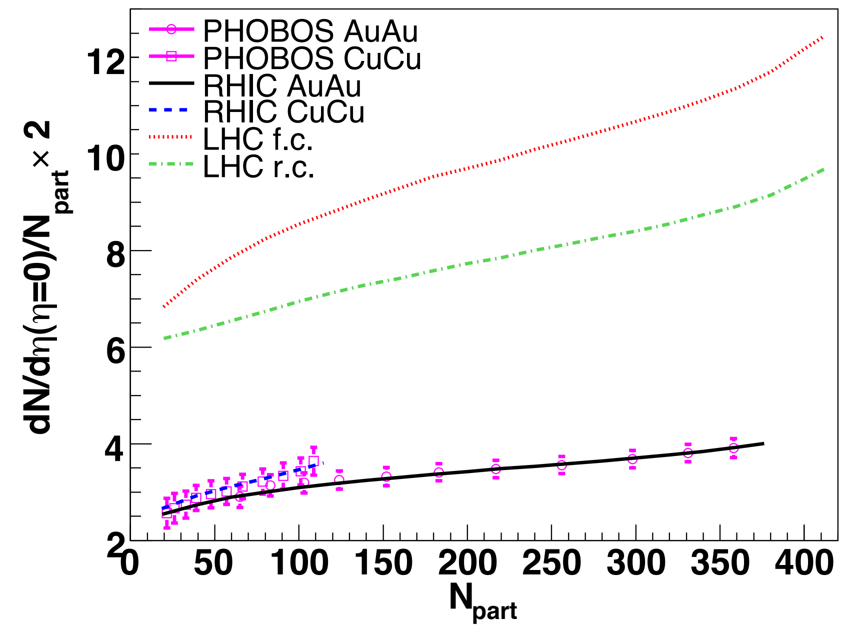
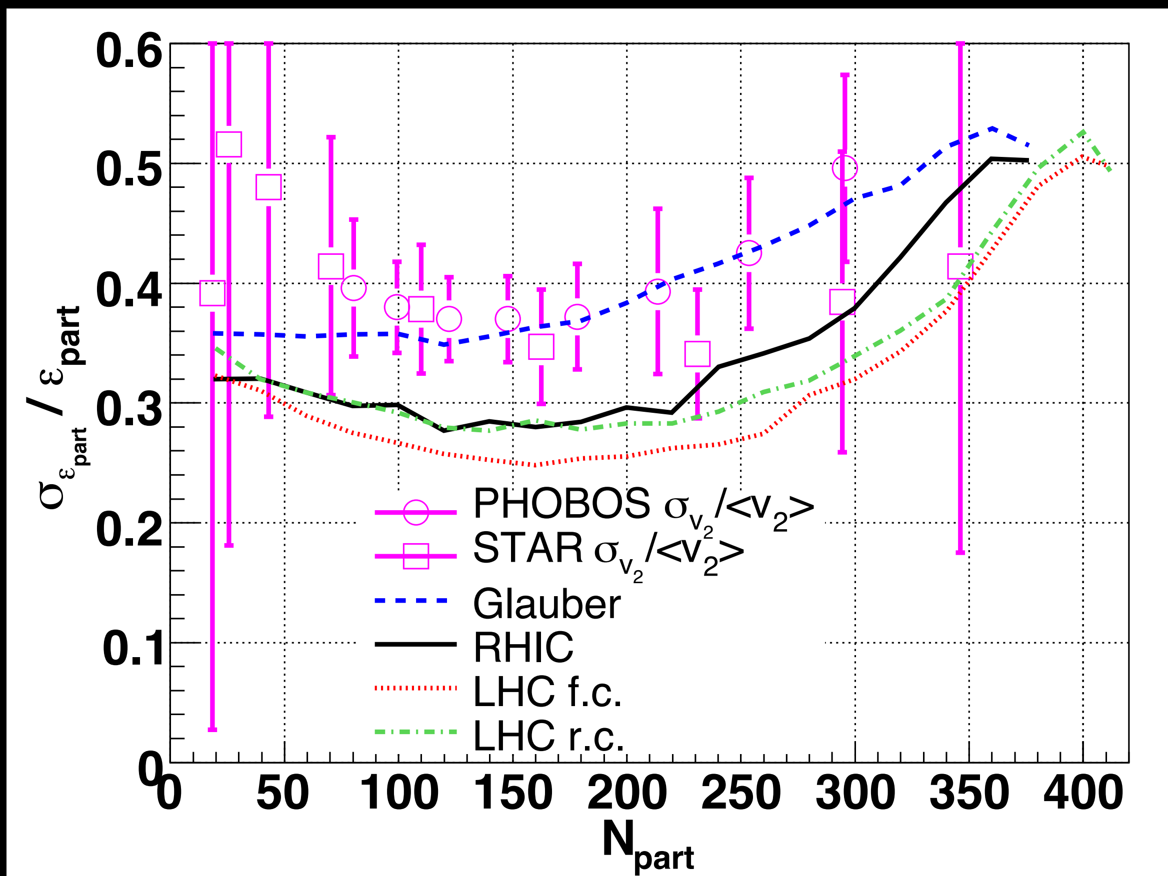


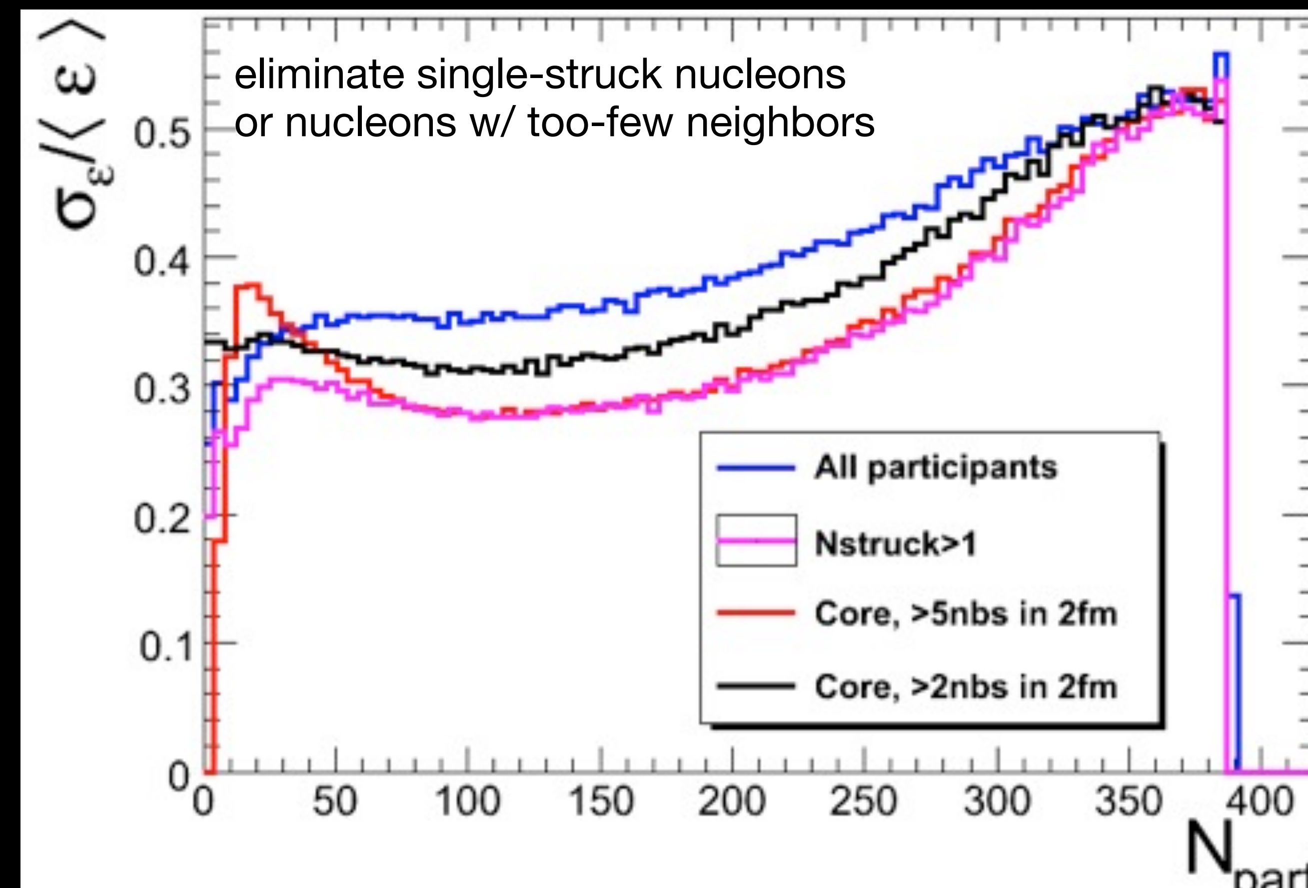
FIG. 1: (Color online) Multiplicity for Au+Au and Cu+Cu collisions at 200 GeV and PbPb collisions at 5500 GeV. The data is from the PHOBOS collaboration[9, 10].

in turn, is measured by counting nucleons in a given sampling area. However, if the radius of the sampling area is $r_{\max} = \sqrt{\sigma_{inel}/\pi}$, one overestimates the interaction probability especially in the periphery, since nucleon pairs can have a distance up to $2r_{\max}$. Therefore, we improved on our previous model by rejecting those pairs with $r > r_{\max}$. In the $p+p$ limit this results in an additional factor 0.58 which is very close to the value found in Refs. [7, 8] by accounting for the difference between the inelastic and the geometric cross section of a nucleon. We further assume here that $\sigma_{inel} = 42$ mb at full RHIC energy ($\sqrt{s_{NN}} = 200$ GeV), and $\sigma_{inel} = 66$ mb at LHC energy ($\sqrt{s_{NN}} = 5500$ GeV).

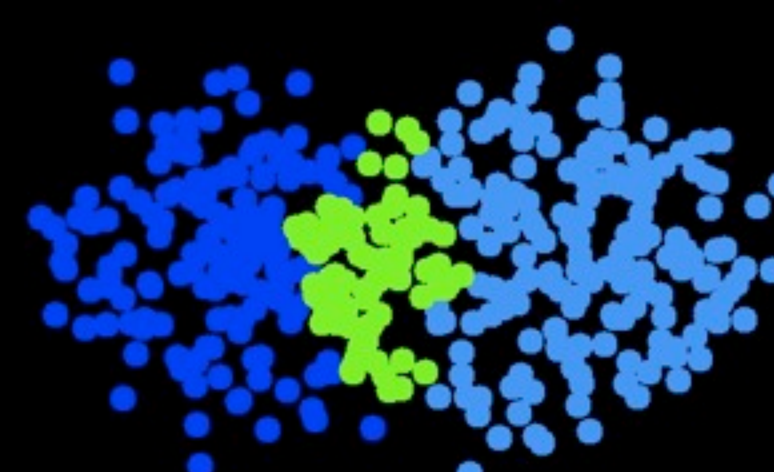
Effect on v_2 Fluctuations

C. Loizides & PAS (Au+Au TGlauberMC v1.1)





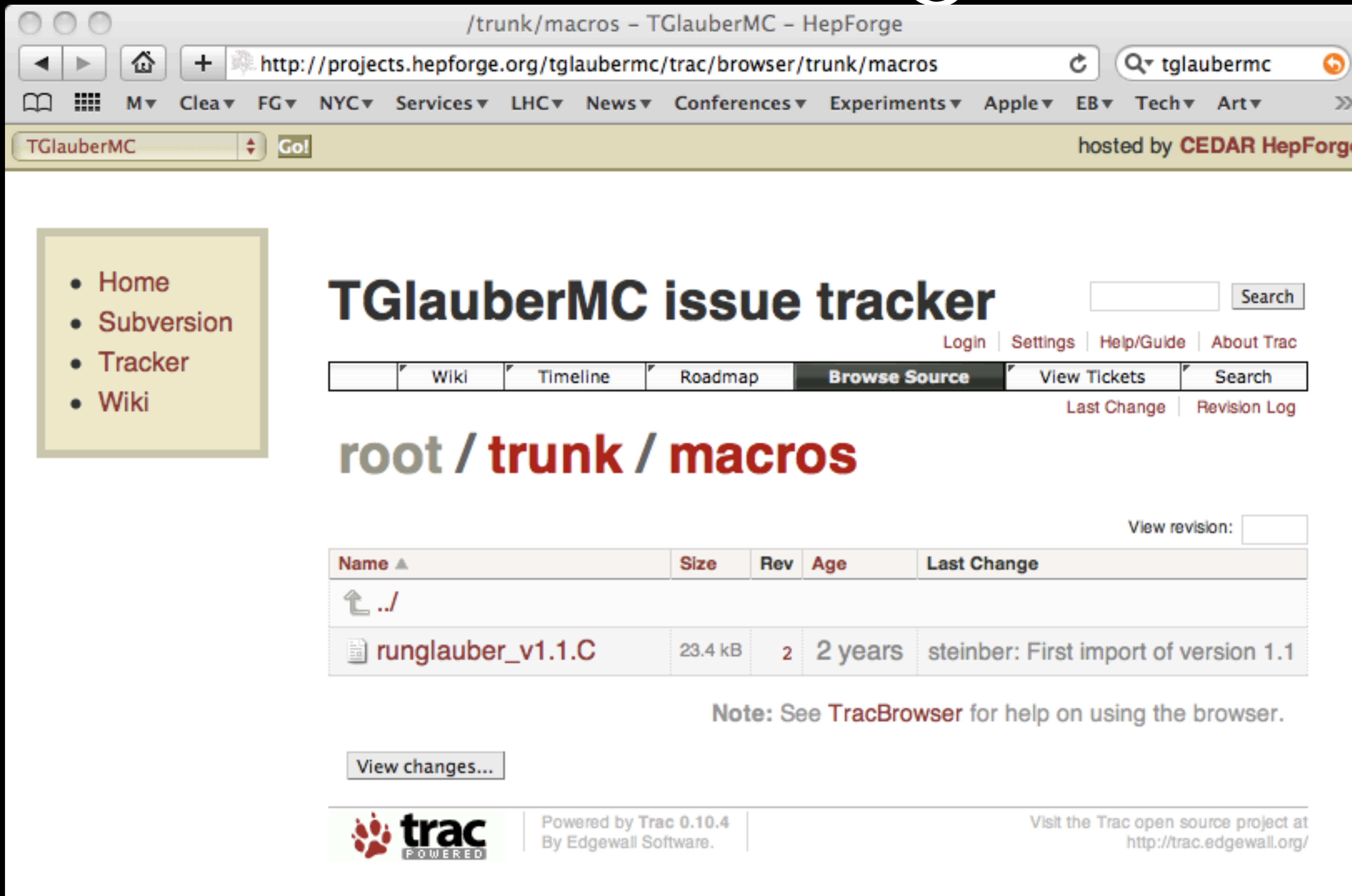
Be careful when you change basic features.
They confuse things when the change is
not understood by the audience!
(And how much of MC-KLN is CGC, and
how much is the modification to Glauber?)



Public Versioning is Fundamental

- **MC-KLN is an example where clear versioning should be used on figures, but it applies to all initial state calculations**
- **Model: we always refer to PDFs by their full names in publications**
  - MRST2004, CTEQ6.1M, EKS98, EPS08, etc.
- **Our models of the initial state should be treated in the same way**
  - TGlauberMC v1.2
  - MC-KLN vs. 1.01
- **Then you are not just using “CGC” initial conditions, but a particular implementation**
  - Will allow theory-to-theory comparisons as well as theory-to-experiment

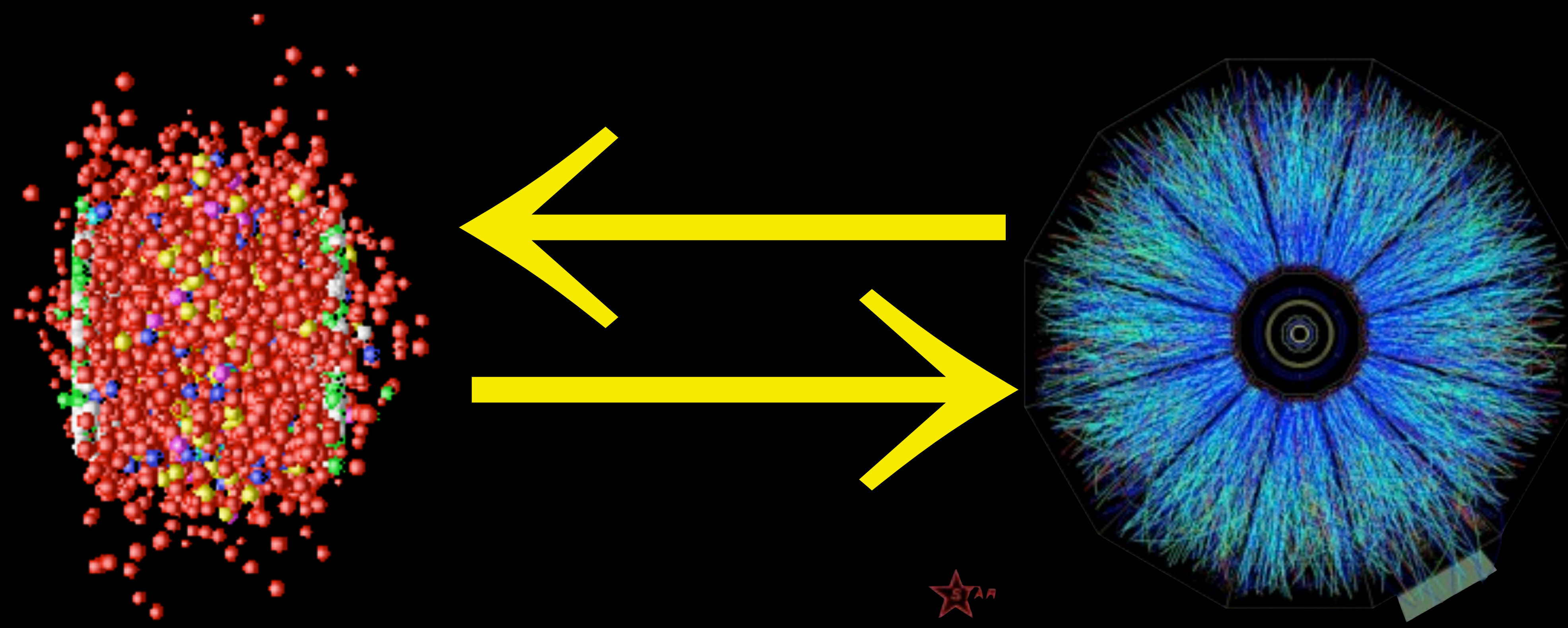
Use HEPForge?



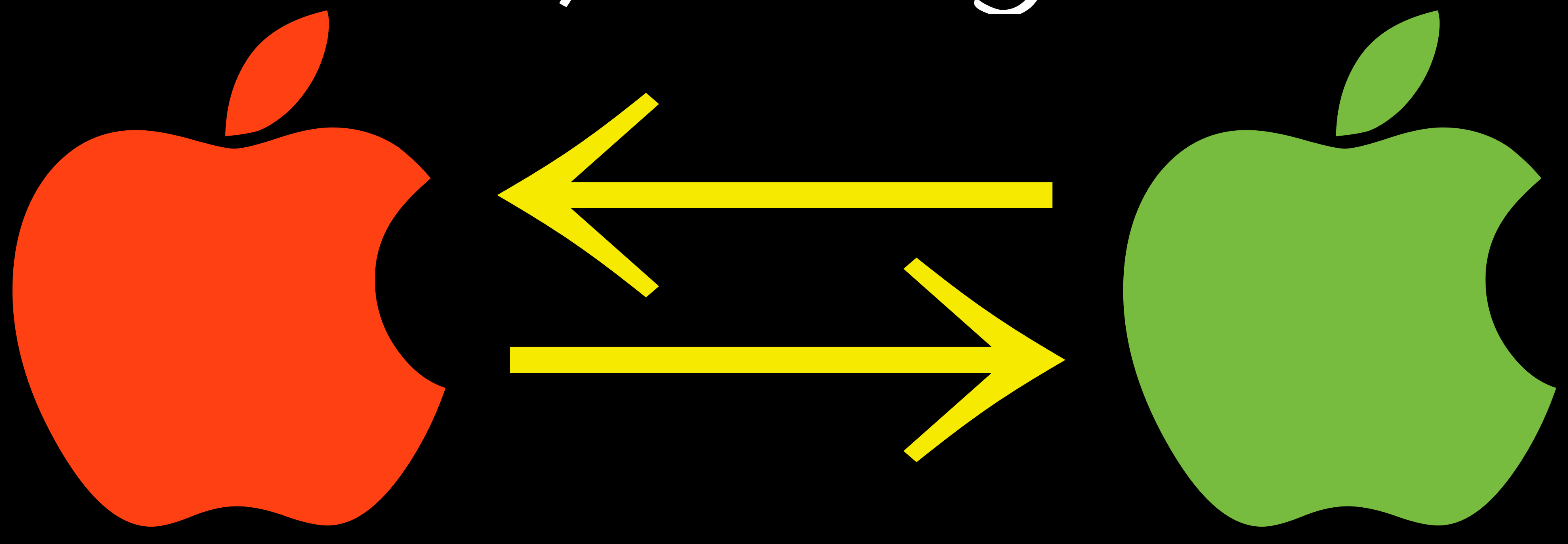
Open source, versioned, etc.

Conclusions

- **Put all of the initial state information up front!**
  - Nuclear density parameters
  - Exclusion radius ("hard core")
  - Maximum radius for interaction ("straggler cut")
  - Two component parametrization (x, α)
  - Optical vs. MC glauber (or CGC variant)
  - Participant plane or standard eccentricity
  - Prefactor in front of S (1,2π,4π,...seen 'em all)
  - Energy or entropy (and EOS if needed)
- **Version numbers for initial state codes!**
  - TGlauberMC, MC-KLN, etc.
- **Always show (& scrutinize) comparisons with data!**
  - Use a twiki or website if you have lots of plots



My charge



Comparing apples with apples: How do experimentalists define centrality classes and, for each such class, N_part, n_ch, <b>, \ecc, etc. and their E-by-E fluctuations? What will theorists have to do, in terms of including or averaging over E-by-E fluctuations, to produce theoretical output that can be directly compared with the data?